AD 605796

U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TRECOM TECHNICAL REPORT 64-26

LOGISTICAL OVER-THE-SHORE (LOTS) SYSTEMS STUDY

Project 1D521801A266
Contract DA 44-177-AMC-23(T)

June 1964

prepared by:

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The need to analytically define complex interphase relationships between the numerous elements of typical logistics-over-the-shore operations under varying operating conditions provides the basis for this study. This command concurs in the analytical techniques used in this Phase I report.

Data related to LOTS have been compiled, and decision rules for varying data in response to varying operating conditions are established. A rationale for computer simulation to test for potential improvements in LOTS productivity is herein developed. In addition, a method of measuring effectiveness of improvement candidates is derived.

The report represents the coordinated efforts of the Department of the Army Project Advisory Group, which includes representatives of Combat Developments Command agencies as well as of this command.

In Phase II of this study, the compiled data and simulation techniques described will be varied through established decision rules to provide quantitative and qualitative bases for follow-on validation testing of those equipments and techniques which show potential for making major productivity improvements. Conclusions and recommendations as shown in this report are considered preliminary, subject to the results of the Phase II effort.

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Project 1D521801A266
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LOGISTICAL OVER-THE-SHORE (LOTS) SYSTEMS STUDY

Phase I Report

Prepared by
American Machine & Foundry Company
General Engineering Division
Stamford, Connecticut

for
U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

PREFACE

This report was prepared by the General Engineering Division of American Machine & Foundry Company, Stamford, Connecticut. It presents the results of Phase I study activity which was begun June, 1963.

Phase I program effort was conduced by an engineering analysis team led by Mr. P. Silverman, Project Engineer. Participating in the study were Mr. G. Bott, Operations Research Analyst; Mr. J. George, Systems Analyst; and Mr. H. Bossung, Development Engineer.

This LOTS study contract is administered by the U. S. Army Transportation Research Command, Ft. Eustis, Virginia. American Machine & Foundry Company and members of the study team wish to acknowledge the advice, assistance and guidance provided by TRECOM personnel. Further, we wish to express our thanks to members of the LOTS Project Advisory Group for their guidance.

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ILLUSTRATIONS

TABLES

SYMBOLS

A	Lighter availability factor representing the percentage of task lighters available for discharge operations.
b	Discharge rate at shore expressed in short tons per hour.
c	Subscript denoting general cargo.
C	Average cargo load per lighter trip expressed in short tons.
d	Lighter loading rate at the ship expressed in short tons per hour.
D	Distance in miles.
f	Percent of normal lighter fuel consumption while loading and discharging cargo.
g	Fuel cost per mile.
h	Hatch discharge rate expressed in short tons per hour.
K_1	Hatch equipment cost per day per hatch gang.
K_2	Shore equipment cost per day per beach discharge location.
K_3	Number of personnel per hatch gang.
K_4	Shore equipment cost per day per beach discharge location.
l	Subscript denoting land.
L	Cost of lighter per day.
LEI	LOTS Expenditure Index.
LT	Long ton (equal to 2240 pounds).
MT	Measurement ton (equal to 40 cubic feet).
n	Number of hatches.

N	Number of ship-discharge groups, i.e., number of complements of equipment and personnel; each complement responsible for the discharge of one ship.
p	Subscript indicating prime lighter.
P	Percent of monthly resupply cargo to be transported in supplemental lighters.
r	Average lighter speed, miles per hour.
s	Subscript denoting supplemental lighter.
ST	Short ton (equal to 2000 pounds).
T	Number of TOE personnel assigned to sustain operation of a lighter on a two shift per day basis.
v	Subscript denoting vehicular cargo.
w	Subscript denoting water.
W	Average number of ships waiting in queue per day at each discharge site.
λ	Average number of ships arriving per day at each discharge site.
μ	Average unloading rate per ship expressed in ships per day.

SUMMARY

In fulfillment of the requirements of the Statement of Work and in accordance with further definition provided by subsequent direction, the prime objective of this study is to derive definitions of optimum equipment and employment concepts for all cargo handling functions relating to Logistical-Over-The-Shore (LOTS) operations.

LOTS operations involve the transshipment of resupply material and personnel aboard ocean shipping to inland modes of transportation on the far shore without reliance on fixed discharge facilities.

Specifically, LOTS operations as defined herein comprise all equipment and activities required to discharge resupply materials from ocean shipping on its arrival at the far shore and to transfer such cargo across the beach to awaiting line-haul transportation at a sustained rate of 1500 short tons per day at each discharge site.

The type of discharge operations concerned include:

1. Unloading cargo from conventional dry-cargo ships anchored relatively close to shore (0 to 5 miles).

2. Unloading cargo from conventional shipping 5 to 50 miles offshore, unanchored and possibly underway.

3. Discharge of mobile equipment from special roll-on roll-off (RO-RO) ocean shipping.

Reported herein are the results of Phase I of the LOTS study. These results include:

1. Establishment of a suitable "yardstick" for measuring the effectiveness of present and proposed LOTS systems, equipment and techniques.

2. Assembly and development of background material relative to equipment employed or employable.

3. Analysis and evaluation of existing LOTS equipment and techniques to determine their influence on LOTS effectiveness.

4. Definition of optimum techniques to be employed using systems now available.

5. Identification of areas of deficiency in present systems and recommendations for suitable improvements.

A computer program has been designed in which LOTS operations are simulated. This program serves as an analytical tool for evaluating LOTS equipment and techniques. A description of the simulation program is available under separate cover in a document entitled "LOTS Simulation — Computer Program Manual".

A separate Phase II report will identify and evaluate recommended equipment, techniques or modifications to existing equipment or techniques as found appropriate to improve and optimize LOTS system productivity. Recommended items will be accompanied by descriptions of technical capability as well as qualitative and quantitative justification.

Final conclusions and recommendations covering the LOTS system analysis conducted in Phase I and the equipment and technique analysis performed in Phase II will be included in the Phase II report.

Phase I study findings and preliminary projections of technique and equipment improvements are described herein.

PHASE I — STUDY FINDINGS

The most realistic measure of the effectiveness of LOTS operations is cost. A "yardstick" herein defined as the LOTS Expenditure Index (LEI) provides a satisfactory quantitative measure of the relative costs of present and proposed LOTS systems. Optimum LOTS operations require minimum expenditure of ship days, LOTS personnel and equipment and are thereby identified with lowest LEI.

The following findings are applicable:

1. <u>Organization</u> - The preferred manner in which to organize present LOTS personnel and equipment is to provide each LOTS site with two groups, each capable of conducting a single-ship, six-hatch-gang operation on a two-shift basis. This arrangement provides minimum LEI.

2. <u>Lighterage</u>

   a. Present lighterage organized in proper quantity and in suitable combination will aid in achieving low LEI. The preferred arrangement of task lighters per site are:
      1) 54 LARC-V's and 3 BARC's
      2) 54 LARC-V's and 3 LCM-8's
      3) 36 LARC-XV's and 3 BARC's
      4) 36 LARC-XV's and 3 LCM-8's

   b. The comparative LEI's for lighterage families one through four are within 5 percent of one another.

3. <u>Personnel</u> - Personnel costs are the major factor influencing LEI's of present systems. Daily manpower contributes approximately 60 percent to the total LEI.

4. <u>Cargo Unitization</u> - With the advent of increased unitization (i.e., use of standardized pallets and containers), reductions in personnel and ship waiting costs are possible by improvements in equipment and techniques of operation.

5. <u>Ship Discharge Operation</u>

   a. Existing ships' gear is overtaxed when used in LOTS operations. Time consumed in landing cargo on lighters and in using the hook to drag cargo in the hold unnecessarily delays activities in the hold and on the lighters.

   b. The use of supplementary winching and/or hoisting equipment would permit parallel operations to be performed and reduce lighter loading time significantly, thereby resulting in improved LEI's.

c. The technique of prestow influences the potential gain achievable from improvements in auxiliary equipment and extensions in the use of unitization. Segregated stowage by nature of package (i.e., only pallets stowed in one level of a hatch) would eliminate the need to readjust equipment constantly and would maximize gains achievable from other improvements.

6. Weather Degradation - Severe sea state and climatic conditions cannot be contended with adequately by current LOTS equipment and techniques. As a result, discharge operations are seriously degraded and frequently cease in periods of bad weather. Significant improvement in LEI could be achieved if LOTS bad weather operational capability were extended.

7. Shore Operations - Existing terminal service company TOE's are organized to permit simultaneous operations at a variety of transit points (on the beach, at railheads, etc.). The prevalence of landing craft in the past required a great deal of heavy hoist equipment and necessitated two cargo transfer operations; one at the beach and one at a transit point. Similarly, increases in Army mobility and use of RO-RO shipping minimize the shore discharge burden. Therefore, decreases in the numbers of personnel and handling equipment would result from careful analysis and test of operations with families of LARC amphibians.

8. Helicopters vs. Conventional Lighterage - Analysis of preliminary economics of the Chinook helicopter indicates that if it is used as a primary means in LOTS operations 0 to 5 miles from shore, a considerably higher LEI than for the preferred systems described in Paragraph 2a will result.

However, when utilized for the currently planned task of priority cargo delivery wherein sustained operational capability is not required and an availability planning factor much higher than the factor applied above is readily obtainable, such helicopters afford an efficient means of mission fulfillment.

PROJECTED TECHNIQUE IMPROVEMENTS

1. Cargo Prestow

   a. Standardization - The feasibility of establishing standardized resupply cargo prestow plans for the various types of merchant ships should be explored. Such plans could be tested and improved to insure efficient discharge as well as satisfactory stowage.

   b. Block Stowage - Existing techniques of block stowage should be extended to include singular cargo-type stowage for entire levels of a hatch (i.e., pallets on one level, drums on another, etc.).

2. Operating Procedure

   a. Anchorage - Ship anchorages should be selected as close to the beach entrance as is safe. Ships should be dispersed only if an active enemy threat prevails, otherwise unnecessarily high degradation in LOTS performance will develop. Ships which afford the highest discharge rate should be assigned closest anchorage to insure minimum degradation.

   b. Transit Areas - Line-haul transit areas should be established as close to the beach as is practical, without exposing the operation unnecessarily to geographic and environmental influences.

   c. Lighterage - BARC's and LCM-8's should be committed to general discharge only when it is confirmed that they will not otherwise be required for removal of heavy lifts. When used in this manner, they should be assigned to the most distant anchorages and/or to hatches containing fast loading cargo.

   d. Hatch Operations - When only one ship is at the discharge site and weather conditions permit, double gangs and double mooring should be used on the double-rigged hatches of that ship. Similarly, as each individual hatch is closed following discharge, the gang should be shifted into a double-rigged hatch to participate in its discharge.

PROJECTED EQUIPMENT IMPROVEMENTS

After analysis to confirm feasibility and establish technical requirements, the following types of equipment should be "jury rigged" and field tested in conjunction with appropriate modified or new techniques.

1. Auxiliary Portable Draft Handling Equipment

    a. Powered drag winches for use in the holds.

    b. Jib cranes for use with each ship's boom and winch capable of swinging drafts onto the deck. (See Appendix).

    c. Gravity conveyors for use on deck.

    d. Drive skid, bridge truss and slave pallets for consolidated discharge of cargo from the deck to lighters and from lighters to line haul.

    e. Draft guide assemblies for guidance of drafts into lighters in heavy seas.

    f. Appropriate slings to accommodate above equipment.

2. Lighter mooring devices to permit safer and quicker mooring of small lighters in heavy seas.

3. Investigation should be continued to ascertain the feasibility of highline operations between BDL's and cargo ships during bad weather conditions.

INTRODUCTION

The employment of over-the-shore logistical resupply was necessitated by the enemy's destruction of fixed ship discharge facilities during World War II. Earliest LOTS operations involved utilization of then existing equipment available in the Army's inventory in improvised stream discharge operations. Such operations made use of DUKW's, LCM's, LCU's, and various land-based heavy construction equipment. These operations were extremely costly and unproductive. Often sea state conditions seriously hampered operations. Long, costly lines of ships awaiting discharge formed. Cargo once brought to the shore often remained there for lack of effective devices for unloading lighters and clearing the beach.

In more recent years, TOE's have been organized and personnel trained for LOTS operations. The goal was to integrate personnel and equipment into a well organized discharge system. Numerous New Offshore Discharge Exercises (NODEX) have been held in which new items of equipment were introduced and personnel trained.

The results of these exercises have emphasized the extreme difficulty of over-the-beach discharge operations and the severe degradation in performance caused by weather and sea state.

New types of amphibians, RO-RO discharge, helicopter lift-off operations and improvements in shore handling equipment all apparently extend LOTS operational and environmental performance capability. But what is the gain and at what cost? How should these and projected equipment be most efficiently utilized? What new devices are needed? These are all serious questions that confront the military planner.

This study seeks to develop a suitable "yardstick" or effectiveness index with which LOTS systems, equipment and techniques can be reliably evaluated. Having established an effectiveness index, existing and notional equipment and techniques are compared by use of analytic procedures including a computer simulation designed for this purpose. Through this procedure conclusions are reached and recommendations made relating to optimization of LOTS operations, consistent with mission objectives.

Mission objectives provided as direction to this contractor by TRECOM include:

1. A daily average resupply of 1500 short tons (ST) with 3 to 25 percent by weight of the daily resupply being vehicular cargo. For the purposes of this analysis, the 25 percent figure will be used.

2. Types of discharge operations to be considered:

   a. Discharge from conventional ships at anchor close to shore (0 to 5 miles).

   b. Discharge from conventional ships unanchored and possibly under way (5 to 50 miles).

   c. Discharge of mobile equipment from special RO-RO ocean shipping.

3. Helicopter discharge shall be considered.

4. Maximize performance consistent with the following factors:

   a. Good weather and the area secure (normal).

   b. Bad weather and the area secure.

   c. Good weather and the area vulnerable (consider levels of ship-dispersion).

5. Study will be confined to far-shore discharge, commencing with the arrival of the ship at the far-shore discharge site and ending at the point of loading cargo onto line-haul transportation.

Considerable guidance material obtained from the library of the Transportation School, Ft. Eustis, as well as interviews and observations, have served as the basis of inputs utilized in this study.

Initial pages of the discussion provide a verbal description of typical LOTS operations. It is believed that this will permit persons not too familiar with LOTS operations to obtain a better understanding of subsequent material presented in this text.

In a subsequent chapter, the concept of "measure of effectiveness" is discussed and an LEI derived. This discussion further identifies those performance factors which must be developed in the text before actual LOTS system comparisons can be made. Subsequent chapters are devoted to the development of qualitative and quantitative information and comparisons of cargo, ship, lighterage and stevedoring characteristics. LEI's developed for various systems and the results are analyzed and recommendations made.

The order of presentation of the material contained in this study is depicted in Figure 1. The numbered balloons adjacent to each box describe the sequence of analysis followed.

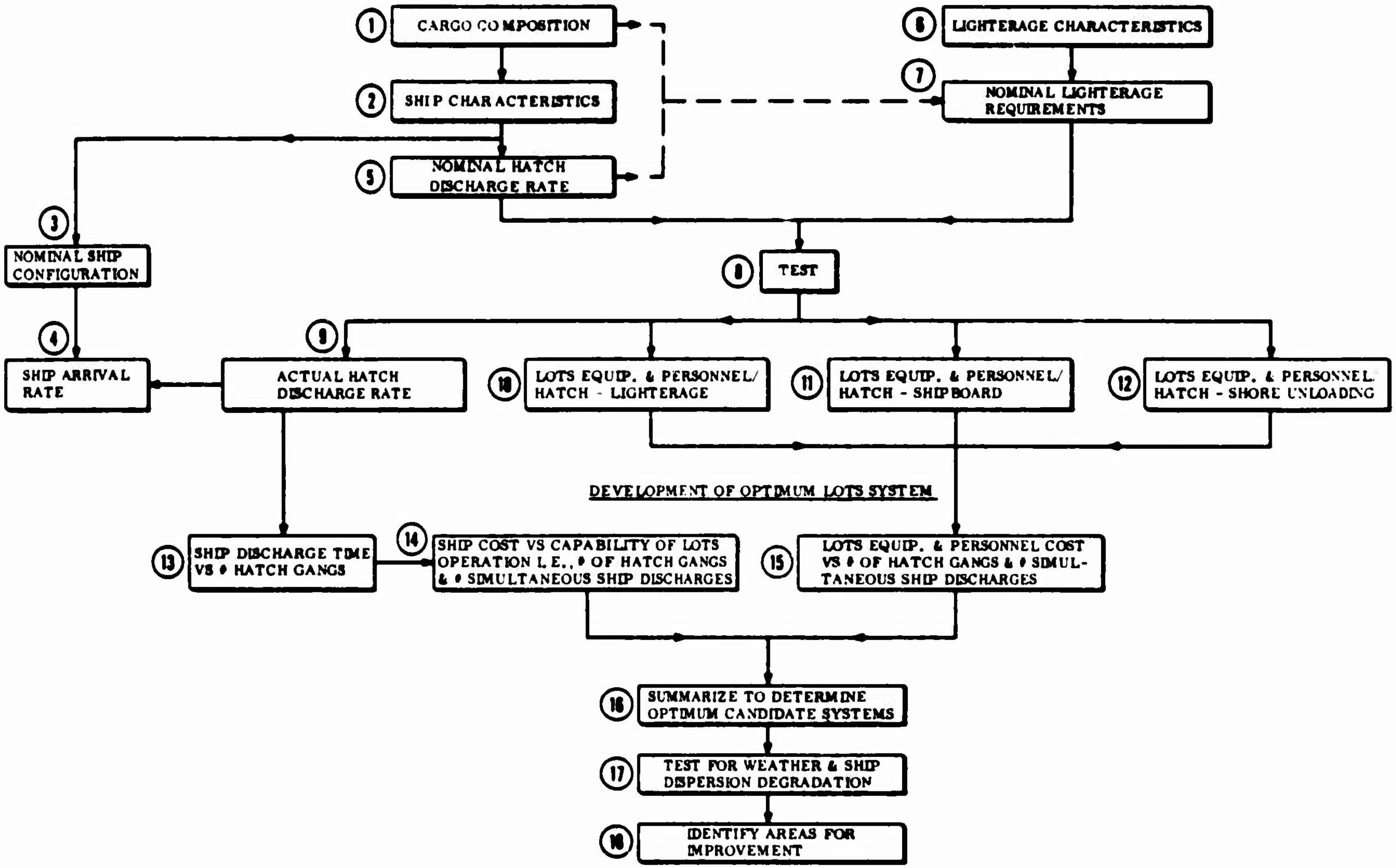

Figure 1. Order of Analysis

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DESCRIPTION OF PRESENT LOTS OPERATIONS

This description of the LOTS operational concept as currently performed in test and as planned for use in this time frame is intended merely to familiarize the reader with current operations, and therefore no comments or recommendations are presented.

CONVENTIONAL SHIP DISCHARGE

Within thirty days after operations are initiated in a combat zone, shipments of resupply will begin arriving on board conventional cargo ships. At that point in time, it is anticipated that fixed discharge facilities have been destroyed or that, if available, they are vulnerable to enemy air attack. The possibility of enemy air attack on ships discharging in stream is considered low. Yet to minimize losses in case of attack, discharge sites, as well as ships at each site, are dispersed at distances up to 5 miles from shore (reference 33). The need for discharging ships 5 to 50 miles offshore may develop. (See paragraph on Conventional Ship Discharge, Unanchored.) Terminal service groups under the command of the Transportation Corps are alerted to the impending arrival of shipping and will have copies of ship manifests. Normally, prior to commencement of discharge operations, a bivouac area is established for the participating units which normally consist of terminal service companies (TOE 55-117D), full-strength amphibious companies (light, medium, and heavy), and/or landing craft as required.

Shore platoon personnel of terminal service companies establish transfer sites in patterns consistent with the road net, depot locations, line-haul equipment characteristics and lighterage characteristics (i.e., landing craft require cargo transfer at the shore line which may necessitate the laying of pierced aluminum planking).

Ship platoon personnel with their cargo gear will board the ship on its arrival and begin opening hatch covers and spotting the rigging (provided deck cargo does not prevent this). In the meantime, lighterage personnel will hook up mooring lines. As soon as possible, priority cargo will be removed from the ship.

A shore platoon leader at the shore line and a ship platoon leader aboard the ship command the lighterage and ship discharge operation respectively. Of primary interest to the shore platoon leader is keeping the lighterage moving and out of deadline. Similarly, the ship platoon leader must prevent bottlenecks from developing aboard ship.

Operations are worked in two shifts, with personnel on board ship having boxed-lunch mess. Lighterage undergoes preventive maintenance and fueling between shifts.

The manner in which each hatch gang operates aboard ship is generally as follows. The gang consists of 15 men: a foreman, an assistant foreman, 2 winchmen, a signalman and 10 stevedores. When feasible, these stevedores subdivide into two groups which move cargo from opposite sides of the hatch to the hook. Conventionally, ships' booms are rigged in a married fall arrangement – one boom over the hatch square (opening) and the other over the side, with a single hook controlled by two ships' winches. Successive drafts are dragged to a position in line with the hook's path, slings are attached, and the draft is lifted out and over the side of the ship into the waiting lighter.

Periodically, dunnage is handled. As successive decks are emptied, hatch boards are removed from the lower decks to expose additional cargo. Frequently, hook lifting operations cease while the hook is used as the tow line for a "make-shift" rig to pull large drafts out from under the wings.

Whenever a draft too large for lifting by the rigging in use is uncovered, operations are halted while booms and rigs are doubled-up to increase capacity.

When sufficient personnel are on hand and sea state permits, hatches equipped with four booms and winches are rigged to permit simultaneous discharge into lighters on both sides of the ship.

Delays resulting from excessive traffic in and out of the hold normally reduce the productivity of both hooks under these conditions. Throughout the operation, as weather permits, lighters continue to operate between the ship and shore discharge locations.

At the shore discharge locations, either cranes or forklift trucks are used to remove the cargo from the lighter and transfer it to line-haul transportation. Frequently, cargo is temporarily stored and assembled on the ground in order to segregate supplies for specific units. This necessitates double handling of the cargo.

ROLL-ON ROLL-OFF DISCHARGE

In recognition of the trend toward increased mobility and in an effort to minimize ship loading and discharge time for mobile equipment, Comet class RO-RO ships are now in operation. Present plans describe the use of 300-foot beach discharge lighters (BDL's) for RO-RO operation.

Through specially designed mooring and tensioning devices, the BDL is able to "marry" to the ramp of a Comet class ship in all but severe weather conditions. Vehicles are driven under their own power from the garage-like ramps and holds of the RO-RO ship onto the lighter. The BDL then disengages and returns to shore, where it beaches with its 600 tons of mobile cargo. The vehicles are then driven off through the beach and inland.

CONVENTIONAL SHIP DISCHARGE, UNANCHORED

A technique of discharge has been tested (references 57 and 80) for possible ultimate use as a means of discharging unanchored conventional cargo ships 5 to 50 miles offshore and possibly under way. The technique involves helicopter operation from portable "wings" installed on the cargo ship and extending outboard of the railings. A winch-driven dolly moves cargo outboard to a position on the end of the wing. The helicopter hovers and attaches to the cargo draft with a special external hook. When the helicopter arrives at a transfer point inland, it can rest the cargo draft directly on the cargo floor of the line-haul vehicle, releasing it automatically on contact.

LOTS MEASURE OF EFFECTIVENESS

This discussion provides derivation of the LOTS Expenditure Index (LEI) and describes its application in this study as the yardstick for comparing LOTS system performance and evaluating equipment and technique capability. All candidate LOTS systems are required to satisfy the mission requirement of sustained discharge of 1500 short tons per day or 45,000 short tons per month at each discharge site. Similarly, each system must meet this objective in all anticipated environmental and operational conditions.

Each LOTS operation involves expenditure of valuable wartime resources: cargo ships, equipment, fuel and personnel. The relative importance of these resources is dependent on the specific wartime situation. For example, under conditions of all-out war, cargo ships will be in short supply. Delays in discharge operation could not be measured merely in added voyage cost. Numerous potential combinations of weighing of these resources are possible. Each combination would have merit in a specific situation; however, which situation is most likely to occur?

The most practical manner in which to attack this problem is to employ the frequently adopted technique of deriving a singular "figure of merit". The "figure of merit" used herein is a direct arithmetic addition of daily personnel and equipment operating and maintenance costs, equipment amortization costs, and ship costs while at LOTS discharge sites:

$$\text{LEI} = \text{Daily Cost of} \left[\begin{array}{l} \text{a) Ships at discharge site} \\ \text{b) LOTS equipment} \\ \text{c) LOTS personnel} \end{array} \right.$$

or

$$\text{LEI} = \sum \left\{ \begin{array}{l} \text{a) Average number of ships at site x daily ship waiting cost} \\ \text{b) Quantity of LOTS equipment } \left(\dfrac{\text{initial cost}}{\text{amortization period}} + \text{operating and maintenance cost} \right) \\ \text{c) Number of operating, administrative and maintenance LOTS personnel x daily cost per person} \end{array} \right.$$

The number of cargo ships required to sustain a 45,000-short-ton-per-month resupply operation depends upon the following factors:

1. Distance to theater of operations.

2. Size and speed of ships available.

3. Stowage loss in each ship resulting from the nature of the prestow cargo.

4. Vulnerability (convoy or single ship passage).

5. Time required for loading and discharge.

6. Delays in ports and at the far-shore discharge site.

LOTS operations influence two of these factors: time required for discharge and delays at the discharge site. All other factors are dependent on the particular wartime situation and independent of LOTS operations.

Ships will not arrive at the discharge site at uniform intervals; variations resulting from time of departure, weather encountered and speed and course of passage will result in a random pattern of arrivals. Departures from the discharge site will also occur at random. If long and costly queues of ships awaiting discharge are to be avoided, then sufficient LOTS capability must be available to minimize this occurrence.

Figure 2 displays general curves which describe the relationship of LOTS operational capability and the resulting daily average number of ships in queue and discharging at a site. These curves indicate that waiting ships and the resulting idleness costs can be minimized by the following techniques:

1. Provide increased LOTS capability to perform multi-ship simultaneous discharge by employing additional ship-discharge groups (i.e., complements of lighters and personnel, each group with responsibility for the discharge of one ship).

   For a specified ratio X_1 (see Figure 2) of ship arrival

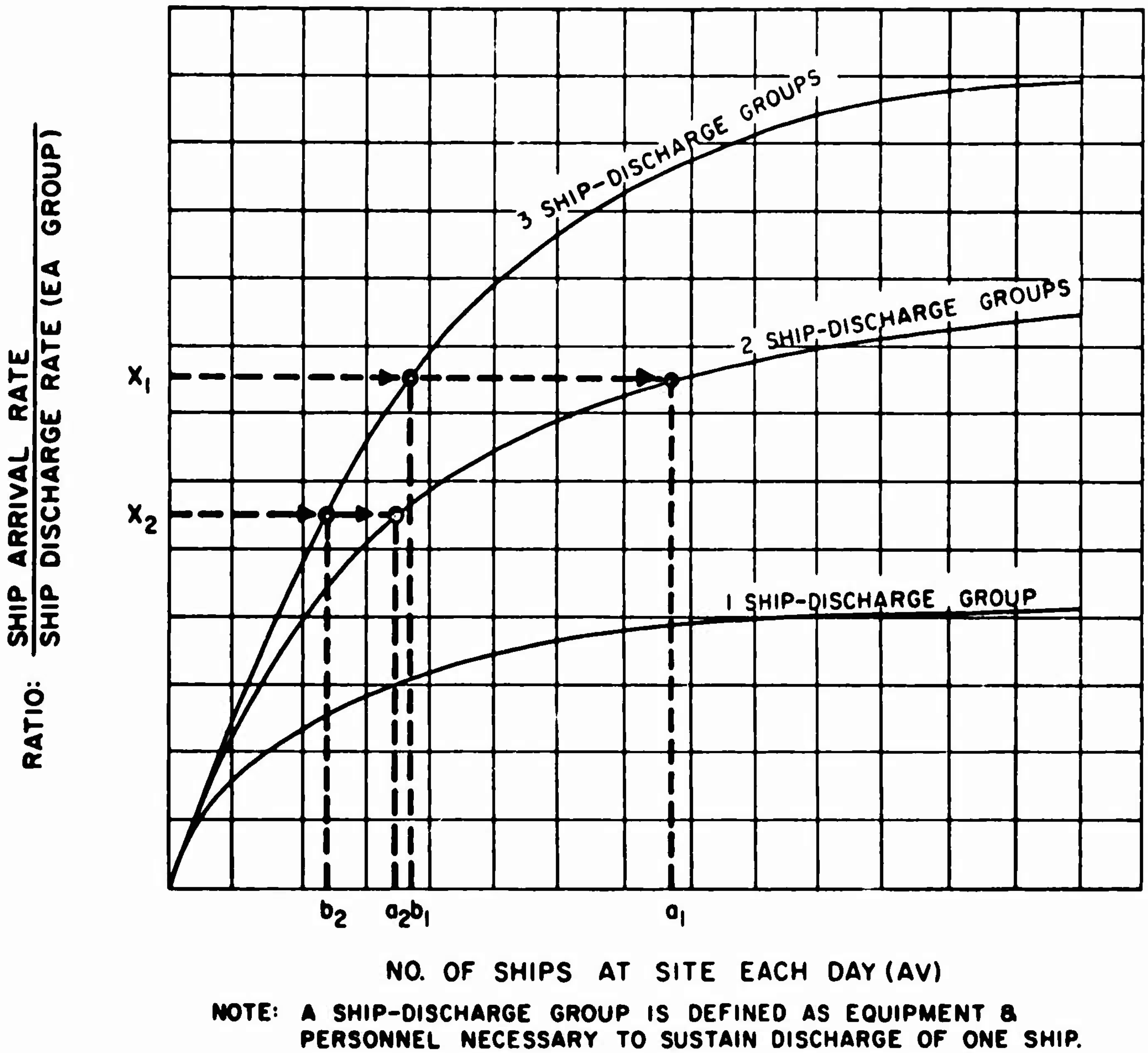

Figure 2. Typical Relationship of Number of Ships at Discharge Site vs. LOTS Operational Capability

rate (based on mission resupply requirement) and ship discharge rate, a two ship-discharge group operation (two ship simultaneous discharge) will result in a daily average of a_1 ships at the discharge site. Employment of three ship-discharge groups will result in a fewer number of ships, b_1.

2. Minimize individual ship discharge time. Were it possible to increase the average ship discharge rate, thereby reducing the ship arrival/discharge ratio from X_1 to X_2, then fewer waiting ships will result for two and three ship-discharge group operations (a_2 and b_2 respectively).

3. Minimize bad weather influence on individual ship discharge rates. Were it possible to increase the average ship discharge rate by improved LOTS performance under bad weather conditions, then the ship arrival/discharge ratio would reduce and fewer waiting ships would result, as described previously.

LOTS system candidates are compared by summarizing the daily cost of the required LOTS equipment and personnel and the resulting waiting ships for the various employment techniques suggested by the ship cost vs. LOTS capability relationships. The optimum LOTS system candidate may not reflect the lowest cost in ship, equipment or personnel categories. Yet the sum of these elements, the LEI, may still be lower than other candidates.

The LEI also provides a satisfactory means of comparing relative weather and distance degradation effects by the application of factors derived in subsequent analysis.

ANALYSIS OF FACTORS AFFECTING LOTS PERFORMANCE

COMPOSITION OF RESUPPLY CARGO

The nature and composition of resupply cargo have a major influence on LOTS productivity by:

1. Influencing the stowage capacity of cargo vessels (i.e., stowage losses normally increase as amount of cargo unitization increases).

2. Influencing the rate at which cargo can be discharged from the ship.

3. Influencing the loading and discharge time of lighters in the operation, thereby affecting the number of discharge trips each day.

4. Influencing the tonnage carried on each lighter trip.

5. Influencing the handling rate ashore, thereby affecting equipment and personnel.

In order to determine the composition of cargo to be handled in LOTS operations, the following sources of information were studied: Operation Research Office Report T-361 (reference 6); American Power Jet Company Report 121-7 (reference 20); U. S. Army Field Manual, FM 101-10 (reference 29) and numerous NODEX reports (reference 43). By comparing specific findings within these reports and by making necessary conservative assumptions to include current resupply philosophies, a typical cargo mix was obtained. The following discussion summarizes the techniques used to determine this cargo mix.

FM 101-10 supply consumption data as refined by recent guidance, is utilized in Table 1 to project the composition by class of resupply to be discharged in LOTS operations. The percentages by weight of the various classes of resupply are then multiplied by 45,000 short tons (ST) (monthly resupply requirement per discharge site) and the results are listed in Table 2.

This monthly resupply will be shipped in conventional dry cargo ships and in RO-RO ships. However, the limited availability of RO-RO ships is expected to necessitate shipment of 50 percent of vehicular tonnage in conventional ships. Thus, it is projected that 39,375 ST (45,000 ST - 50 percent of 11,250 ST) resupply cargo will arrive monthly aboard conventional ships and 5,625 ST of vehicles will arrive monthly aboard RO-RO ships.

TABLE 1
DAILY RESUPPLY REQUIREMENTS

Class	Consumed per man in theater, Army + Air (lbs/day)[1]	Projected resupply to be discharged by LOTS (lbs/day)	Percent by weight of projected re-supply discharged by LOTS
I	6.80	6.80	11.0
II & IV Less vehicles	14.28	14.28	23.1
II & IV Vehicles	.65	15.47[2]	25.0
IIA & IVA	3.65	3.65	5.9
III Bulk POL	13.70	0	
Packaged & solid	9.20	9.20	14.8
IIIA	17.12	0	
V	8.23	8.23	
VA	4.26	4.26	20.2
Total	77.89	61.89	100.0

1. Reference 29.

2. Equivalent to 25 percent of total tonnage by weight, reference, page 8 paragraph 1.

Physical characteristics of the various classes of resupply are utilized in Table 2 to project the extent and manner of unitization of resupply cargo aboard conventional dry cargo ships. Vehicular characteristics data used in this table are derived from weighted averages of the vehicles required by three infantry and one armored division as listed in Table 3.

TABLE 2
MONTHLY RESUPPLY ABOARD DRY-CARGO SHIPS BY CLASS

Class	ST/45,000 ST of Resupply Required	ST/39,375 ST on Dry Cargo Ship	Factor (ST to MT)	Net MT	Percent by Volume Not Unitized (a)	MT Not Unitized	MT Unitized on Pallets	MT Unitized in Containers
Class I	4,944	4,944	2.1 (b)	10,382	0		10,382	
Class II & IV Less Vehicles	10,383	10,383	1.9 (c)	19,728	50	9,864		9,864
Class IIA & IVA	2,654	2,654	4.0 (b)	10,616	100	10,616		
Class III Pkg'd	6,688	6,688	1.5 (b)	10,032	75	7,524		2,508
Class V	5,984	5,984	0.9 (b)	5,386	25	1,347	4,039	
Class VA	3,097	3,097	0.9 (b)	2,787	25	697	2,090	
Vehicles	11,250	5,625 (d)	3.37 (e)	18,844	100	18,844		
	45,000	39,375		77,775		48,892	16,511	12,372

a. Reference 20.

b. Reference 24.

c. This figure is obtained by taking a weighted average of the elemental factors to convert ST to MT. Factors are obtained from reference 24, Page 355, and percentage of each item is obtained from reference 29.

d. It is estimated that 5625 ST, e.g., 50 percent of the total of vehicular cargo will be transported via RO-RO ships.

e. Reference Table 3.

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TABLE 3
VEHICULAR DATA

Organization	Number of Vehicles	Short Tons	Measurement Tons	Area in Sq. Ft.
ROCAD (Armored) 1 Required	5,124	42,880	129,493	705,574
ROCID (Infantry) 3 Required	10,896	57,720	209,997	1,250,184
Totals	16,020	100,600	339,490	1,955,758
Average per Vehicle	-	6.3	21.2	122.1

(References 29 and 89)

Finally, in Table 4, the resupply composition is identified by type of unit load (i.e., container pallet, drum, vehicle, general cargo). Projections are made of the number of drafts as well as gross short tonnage and measurement tonnage.

CARGO SHIPS AND PRESTOW CHARACTERISTICS

Description of Ships

Cargo ship data used in this report has been obtained chiefly from the Merchant Ship Register, MSTS; prestow plans, Brooklyn Army Terminal; and references 11, 24, and 92. A tabulation of ship characteristics is shown in Table 5.

The nature of cargo handling equipment on merchant ships today is varied. In addition to basic differences between ship types, ship owners have made modifications to their ships from time to time replacing and adding heavy lift equipment and gantries. It is therefore not correct to assume that all ships of a particular class are equipped with common equipment. The vast majority of ship hatches are equipped with pairs of 5-ton and/or 10-to booms which are conventionally

TABLE 4
MONTHLY RESUPPLY ABOARD DRY CARGO SHIPS BY UNIT LOADS

UNIT LOAD	NET MT	NET ST	NET ST/DRAFT (a)	MT/DRAFT (a)	NUMBER OF DRAFTS	GROSS ST	GROSS MT
Containers:							
Class II & IV	9,864	(c) 3,850					
Class III	2,508	1,672	2.6	9.1	2,123.8	7,115	19,327
	12,372	5,522					
Pallets:							
Class I	10,382	4,944	0.67 (d)	1.4 (a)	7,415.7	12,564	16,512
Class V & VA	6,130	6,811	0.78 (d)	0.7 (e)	8,751.1		
	16,512	11,755					
Drums	7,524	5,016	1.62	2.42	3,096.3	5,016	7,524
General Cargo:							
Class II & IV	9,864	(c) 6,533	1.1	2.16	10,415.4	11,457	22,523
Class IIA & IVA	10,616	2,654					
Class V & VA	2,043	2,270					
	22,523	11,457					
Vehicles	18,844	5,625	6.3	21.2 (f)		5,625	18,844
Dunnage (b)					286	315	
TOTALS	77,775	39,375				42,092	84,730

a. Underlined values are used to compute the number of drafts. Their origins are as follows:

Containers — A statistical average of NODEX prestow data yields 3.35 ST/CONEX. Subtracting 0.75 ST Tare weight provides 2.6 ST Net. Pallets — MT/Draft data is obtained from GAMBODEX shipments, reference 6, for Class I, V and VA items. Drums — ST/Draft is based on 6 drums per lift at 0.27 ST each. General Cargo — ST/Draft was assumed based on University of California time study data, reference 3. Vehicles — see Table 3.

b. From interviews with Brooklyn Army Terminal personnel, average dunnage equals 5,000 board feet per hatch. This is equivalent to 8 ST/Hatch. This study assumes 8 ST of dunnage per 1,000 ST's of cargo.

c. From Table 2 it is noted that 50 percent by volume of Class II and IV is unitized, however, percent unitized by weight equals 37 percent. This is obtained by segregating those items of Class II and IV that do not lend themselves to containerization, e.g., ordnance, ordnance vehicle parts, and engineering construction equipment.

d. Gross ST/Draft = 0.78 is obtained by taking the weighted average of the number of drafts of pallets multiplied by the weight of each draft (including 0.05 ST Tare weight) for Class I, V, and VA units.

e. Gross MT/Draft = 1.02 is obtained by taking the weighted average of the number of drafts of pallets multiplied by the MT/Draft of the Class I, IV and VA units.

f. Reference Table 3.

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TABLE 5
DRY-CARGO SHIP CHARACTERISTICS

Ship Type	Total Bale Capacity (MT)	Hold Bale Capacity (MT) 1	2	3	4	5	6	7	
C1	10,900	1,890	2,860	2,660	1,890	1,640			$2,201[1]
C2	13,400	2,020	3,080[d]	3,290[xd]	3,260[d]	1,770			3,040[1]
C3	18,400	3,020[d]	3,730	4,800[xd]	3,380[d]	3,040[d]			2,677[1]
Victory	11,300	1,760	1,920	3,400[xd]	2,510[xd]	1,740			
Liberty	11,900	2,050	3,370	2,090	2,060	2,070			
C4 (Mariner)	18,400	1,160	2,230[d]	3,790[d]	4,040[xd]	2,810[d]	2,910[xd]	1,480	3,695[1]
C4 (Challenger)	16,100	1,420	2,160[d]	4,470[d]	4,730[xd]	1,930[d]	1,360		

d Double-rigged hatch.

x Heavy lift capacity.

1 Data obtained from Reference 55, excludes port charges and cargo costs.

rigged for "married fall" and driven by pairs of electric winches. When rigged in this manner, these booms have a safe working load of 4 long tons (LT) and 8 LT respectively. No refitting of these ships with higher capacity and/or faster equipment is likely to occur unless financed by the Government. The influence of these ship limitations will be studied in subsequent analyses of lighterage performance.

In addition to ships described above, there are several classes of customized container ships. Many of these ships are now in use and it is likely that still more will be built. For the most part, these ships afford both high space utilization and rapid loading and discharge of specific container and van designs. Feasibility and economic studies of the use of container ships for military resupply involve consideration of the entire logistics/resupply chain, from original commodity manufacturer in the Zone of Interior (ZI) to the ultimate user in the combat zone. Such studies and considerations are outside the scope of this study.

Cargo Prestow

Experienced ship prestow planners interviewed at the Brooklyn Army Terminal state that they are consistently able to accomplish stowage losses of less than 20 percent (measurement tonnage of cargo divided by ship's bale capacity). Estimates made of prestow on NODEX ships (reference 43) reveal stowage losses of approximately 30 percent.

After developing the projected cargo makeup summarized in Table 4, an approximate analysis was performed to determine stowage losses for that cargo mix in C1, C3, and C4 Mariner ships. It was concluded from this investigation that 30 percent stowage loss would represent a reasonable estimate.

Average Dry-Cargo Ship Capabilities

Data obtained from MSTS (reference 39) and the Shipbuilders Council of America served as guides in estimating the numbers of ships which would be available during the 1965-1970 and 1970-1975 timeframes as shown in Table 6. Based upon the anticipated number of active conventional dry cargo ships for each timeframe, and their respective bale capacities, the representative bale capacity of the average ship which would be available for LOTS operations in both timeframes was computed at 14,800 MT's. Considering the projected stowage loss of 30 percent, the average conventional dry cargo ship will transport 10, 360 MT of resupply cargo in its holds.

TABLE 6

DRY-CARGO SHIP AVAILABILITY

Ship Types	Qty. Active[1]	Qty. Laid-up[1]	In Construction '64-'65[1]	Estimated Qty. Available '65-'70 Timeframe[2]	Estimated Qty. Available '70-'75 Timeframe[2]
C1	12	60		12	12
C2	184	17		184	184
C3	166	7	6	172	172
Victory	59	169		171	157
Liberty	44	859		44	44
C4(Mariner)	46		13	59	59
C4(Challenger)	16		17	75	152
Totals	527	1112	36	717	780

1. Reference 39.

2. These quantities are estimates based on the following data obtained from MSTS;

   a) Reference: Shipbuilders Council of America - 1962:

	'64-'65	'65-'70
Ships reaching end of economic life	- 99	33
New ships to be contracted for	- 53	96

   b) Ships reaching end of economic life will be placed in reserve fleet.

   c) It is assumed that 200 reserve fleet ships will be reactivated in the event of war. (During Korean conflict, 200 ships were reactivated).

   d) The bale capacity of ships to be constructed is estimated by the Committee of Steamship Lines as follows: 80 percent of Challenger capacity, 20 percent of Victory capacity.

In addition to the cargo stored below deck, the area above deck at each hatch can be utilized to carry vehicles. This area was analyzed graphically for each hatch for each type of cargo ship. By taking a weighted average of the ships tabulated in Table 6, it was determined that an average deck area of 9000 square feet is available and will accommodate approximately 44 vehicles, considering 60 percent utilization of floor space. At 21.2 MT per vehicle, as taken from Table 3, the additional resupply measurement tonnage per ship carried on deck equals 930 MT. The total average dry cargo ship capability is shown in Table 7.

TABLE 7
AVERAGE DRY-CARGO SHIP STOWAGE

	Gross MT Resupply Cargo	Gross ST[1] Resupply Cargo[1]	Net ST[1] Resupply Cargo[1]
Below Deck Stowage	10,360	5,333	4,974
Deck Stowage	930	276	276
Totals	11,290	5,609	5,250

[1] Reference - Table 4.

It is therefore projected that the LOTS mission requirement of 45,000 ST of resupply per month will be transported to each site as follows:

7.5 dry cargo ships	@ 5246 ST Net =	39,375 ST
1 RO-RO ship	@ 5625 ST Net =	5,625 ST
Total monthly resupply tonnage	=	45,000 ST

Influence of Randomness of Ship Arrivals and Departures

As previously described, ship arrivals and departures at LOTS sites will be random occurences. Inability to cope with these irregularities can result in the formation of large queues of ships awaiting discharge. Historically, there is sufficient proof of the disastrous consequences of this condition to warrant serious consideration in this study. As a result, an analysis is performed here, utilizing queueing theory which later serves as an element in the determination of LEI's.

The equation which describes the steady-state solution to this problem of random ship arrivals is as follows (reference 41):

Average number of ships at site $= \frac{\lambda}{\mu} + W$

Where

$$W = \left[P_0 \, (\lambda/\mu)^N \, (\lambda/\mu N) \right] / \left\{ N! \left[1 - (\lambda/\mu N) \right]^2 \right\}$$

and where

$$P_0 = \left[(\lambda/\mu)^N / \left\{ N! \left[1 - (\lambda/\mu N) \right] \right\} + \sum_{k=0}^{N-1} (\lambda/\mu)^k / k! \right]^{-1}$$

Definition of symbols:

W = Average number of ships waiting in queue.
λ = Average rate of arrival of ships (ships/day).
μ = Average rate of ship discharge (ships/day) by one ship-discharge group.
N = Number of ship-discharge groups at 1 group per ship.
$\lambda = \frac{7.5 \text{ dry cargo ships}}{30 \text{ days}} = 0.25 \frac{\text{ship}}{\text{day}}$.

Solving these equations for 1, 2, and 3 ship-discharge groups, the results are plotted in Figure 3 in terms of hours per ship discharge ($\frac{24}{\mu}$). In addition, the average daily cost per cargo ship ($3, 000) is plotted. This figure was arrived at by a weighted average of active ship quantities and costs provided in Table 5, wherein it was assumed that Victory and Liberty ship daily costs are equal to C1 costs and that Challenger daily costs are equal to Mariner costs.

Figure 3 permits direct determination of ship cost for any specified average ship discharge time and for LOTS organizations capable of performing up to three ship simultaneous discharge. Thus, as an illustration, the employment of a LOTS organization with capability of discharging two ships simultaneously (2 ship-discharge groups), at 140 hours each, will result in an average daily ship cost of $9000.

ANALYSIS OF CONVENTIONAL SHIP DISCHARGE RATES

A major factor in organizing any "throughput" system such as a LOTS operation is an analysis of the product generator. In this case, the product is cargo and the generator is the ship discharge system. The productivity of the ship discharge system is a function of the following factors:

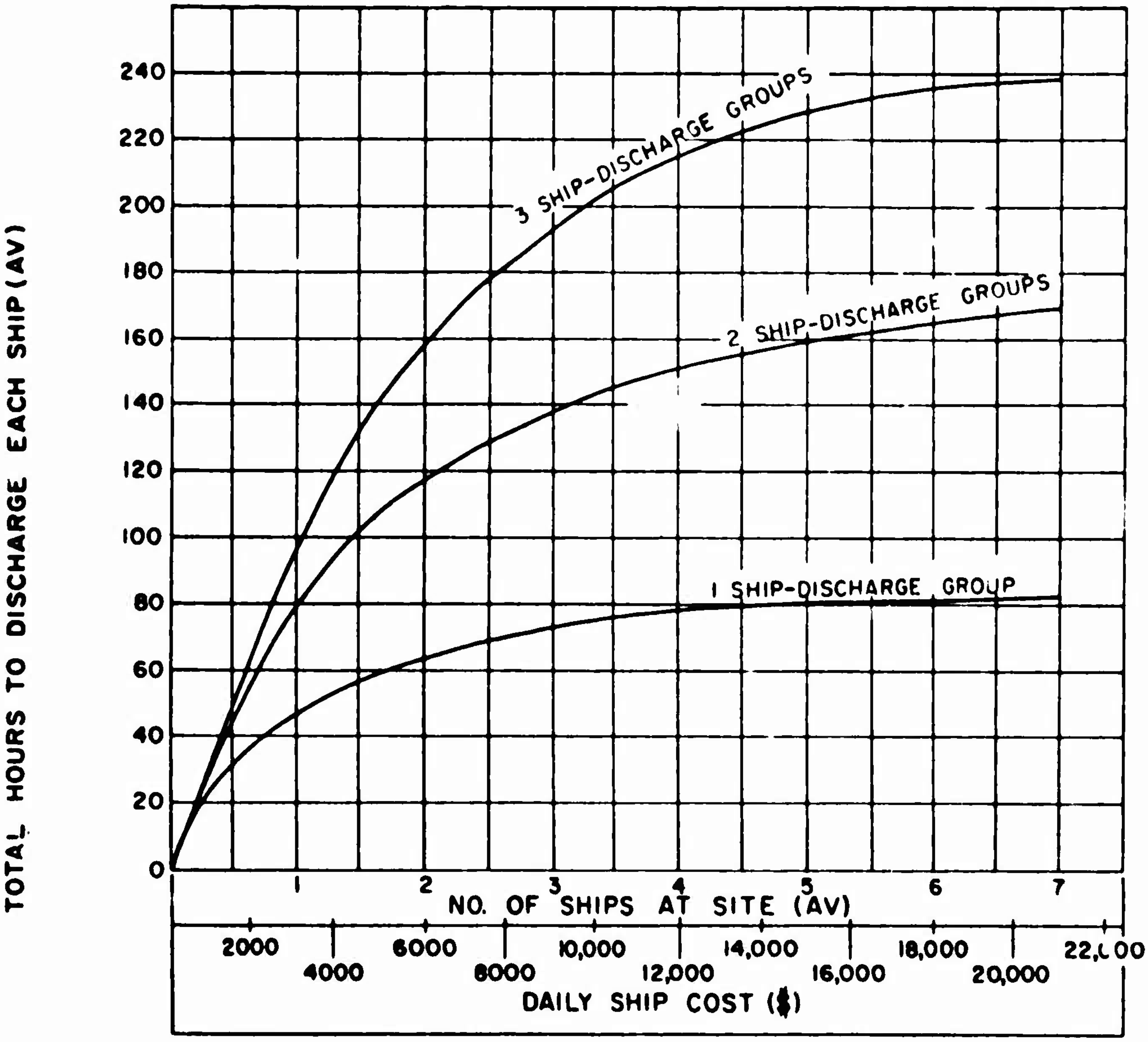

Figure 3. Number and Cost of Ships at Discharge Site vs. Ship Discharge Time

1. Number of Hatches - Each hatch of a ship may be envisioned as a separate staging platform through which a discharge operation proceeds independently of events in other hatches. Thus the more hatches available for discharge, the greater can be the total ship rate of discharge.

2. Number of Sets of Rigging Gear per Hatch - Present techniques of rigging restrict one set of booms and winches to a single hook. Hatches equipped with double rigging afford the opportunity of operating two hooks and loading two lighters simultaneously. Under such conditions, some delays are incurred because of the excessive traffic in the hold and through the hatch. It is reasonable to assume that a 20 percent productivity loss will occur on each side of the hold.

3. Hook Cycle Speed - The hook cycle is composed of preparing load for hoist, hoisting load, positioning load over lighter (or pier), preparing for return of hook, and returning hook. Studies conducted by the University of California (reference 3) and Pinetree exercises (reference 6) have found the hook cycle to be the longest single element or link in the over-all ship discharge cycle most of the time, thereby frequently necessitating delays in other links.

4. Hatch Gang Efficiency. - This factor encompasses both cargo handling techniques and skills as well as physiological effects. Although a hatch gang is trained in the basic techniques of hatch operation, each new ship presents a new challenge because of the individuality of its cargo prestow arrangement. The nature of the gear available to the stevedores equally influences their performance.

5. Nature of Cargo - Unitized cargo decreases the burden on stevedoring personnel but requires new techniques and equipment for manipulating large drafts from the wings of the hold. The net effect is to speed up cargo discharge by virtue of fewer hook cycles and less time-consuming preparations in the hold.

6. Prestow Efficiency – The goal of ship prestow planners is to make maximum utilization of ship space and deadweight tonnage capacity while providing maximum safety to the cargo and personnel. A secondary goal of the planner is to minimize ship loading time by attempting to minimize and equalize gang hours required for stowage in each hold. Although these principles form the basis of economical prestow, shortsightedness relating to ultimate discharge requirements results in inefficiencies. Numerous examples can be cited where stevedore gangs at the destination encountered containers with missing lifting eyes or pallets with crushed edges. In many cases, the cargo was defective before it was loaded onto the ship. In other cases, shifting cargo, caused by faulty prestow, resulted in the spewing of cargo and the dislodging of palletized loads. This cargo must be handled and removed from the holds at considerably less efficiency than unit cargo. "Long" hatches are occasionally found in a ship that require as much as 50 percent more time to discharge than other hatches on the same ship.

7. Delays – Delays which occur during discharge fall into two basic categories: unavoidable and partially avoidable.

   Unavoidable Delays

   a. Dunnage handling
   b. Shifting cargo
   c. Rigging
   d. Equipment failure
   e. Opening lower hatch
   f. Repositioning lighter
   g. Moving vessel
   h. Closing of hatches and operational slowdown (weather, sea state)

Partially Avoidable Delays

a. Waiting for lighters
b. Mealtime
c. Changing of gangs

8. Weather and Environmental Effects — Weather affects both ship and lighter discharge operations. The effect of weather on lighters will be discussed elsewhere in this report. The most obvious effect that bad weather has on ship operations involves the difficulty with which cargo is swung from the hold onto the lighter. Wind effects and sea state severely delay the hook cycle. Ice and rain further affect conditions on deck as well as hamper operations in the hold (hatch tents reduce the severity of this factor). Lastly, a rolling ship induces increased difficulties in moving and positioning cargo in the hold.

Numerical Analysis of Discharge Rate

Several studies have been made in the past of loading and discharge aboard conventional cargo ships, the most well known of which is the University of California Field Study, 1953 (reference 3). None of these studies were able to establish a consistently accurate level of correlation of the various factors affecting discharge productivity.

The scope of the present study did not include field work to obtain new data; therefore it was essential that maximum use be made of existing information. Careful review of the guidance material revealed the existence of a limited amount of information of in-stream discharge of Army resupply cargo. This data included time studies made at Pinetree exercises 1953, as recorded in an Operations Research Office (ORO) report (reference 6), and summary information contained in NODEX reports (reference 43).

Neither set of data affords the analyst a complete insight into all events occurring at the time readings were taken. Therefore, the major value of the data is as a tool, affording comparison of relative handling rates of various types of cargo and of transfer into various types of lighters. The reader is cautioned not to overemphasize the specific quantitative results.

Time studies recorded during Pinetree exercises have been described as representing the discharging activities of nonproficient personnel. As such, their use would appear to be particularly meaningful in this study since it is reasonable to expect that in wartime, personnel with a minimum of training will be performing these activities. It is recognized that these activities were performed under ideal weather conditions; hence, weather degradation factors need be added. The data available is in the form of a series of stop-watch readings recorded during the discharge of various types of cargo into several classes of lighters.

The discharge rates in Table 8 were derived by averaging the mean times for each of the various elements of the unloading cycle as tabulated by ORO (reference 6).

TABLE 8
AVERAGE CARGO DISCHARGE RATES IN MINUTES

Element	Pallets	Containers	Nets	Drums	Vehicles
Prepare load for hoist	0.89	2.19	2.23	1.40	4.66
Hoist time	0.83	0.83	0.83	0.83	5.27
Position load over lighter	0.63	0.99	0.61	0.67	1.99
Prepare for return	0.35	0.37	0.64	0.67	1.33
Return time	0.63	0.63	0.63	0.63	1.68
Minutes per Draft	3.33	5.11	4.94	4.20	14.93

Having established the ST and MT per draft in Table 4, the nominal hourly discharge rate for each type of cargo is hence developed and shown in Table 9.

TABLE 9
NOMINAL CARGO UNLOADING RATES

	Pallets	Containers	Nets	Drums	Vehicles
Drafts/Hr.	18.0	11.7	12.1	14.3	4.0
ST/Draft	0.8	3.4	1.1	1.6	6.3
ST/Hr.	14.1	39.2	13.4	23.2	25.4
MT/Hr.	18.4	106.5	26.4	34.6	85.5

Factors Degrading Unloading Rate

The most significant factors which degrade the nominal cargo unloading rates are delays on board the ship, weather influence on lighters loading alongside and finally lighter unavailability.

Numerical Analysis of Delay

During Pinetree exercises, all delays were timed and recorded. NODEX 11 and 12 (reference 43) reported the nature and time of delays. These data are compared in Table 10. In anticipation of the inefficiencies of wartime operation, the 13 percent delay recorded in NODEX for the bracketed activities is accepted for use in this report rather than the Pinetree results. The resulting total unavoidable delay accounts for 16.2 percent of the total working hatch hours.

During the Pinetree exercises, 802 hatch hours representing 43.5 percent of the working hatch hours were recorded as lost because of partially avoidable delays. Of these hours, 422 resulted from delays caused by insufficient lighters. The remaining 380 hatch hours of delay, representing 20.6 percent of the working hatch hours, resulted from shipboard causes. Lighter unavailability delays can be minimized by providing sufficient lighters. The other partially avoidable delays can be significantly reduced by improved planning. This study assumes that 50 percent of partially avoidable shipboard delays will remain uncorrectable and therefore considers that unavoidable delays will account for 10.3 percent + 16.2 percent = 26.5 percent of working hatch hours.

TABLE 10
UNAVOIDABLE DELAYS

I Unavoidable Delays	Delay Hours	II Pinetree % of Discharge Hours	III NODEX % of Discharge Hours	IV Revised Delay Hours
Dunnage Handling	44			
Open Lower Hatch	25			
Rigging	50	7	13	240[a]
Equipment Failure	9			
Shifting Cargo	15			15
Reposition Lighter	8			8
Backload Cargo	21	3.2		21
Moving Vessel	6			6
High Winds (occasional)	9			9
Total Unavoidable Delay	187			299

Net Discharge Hours
Reported = 1846

$$\frac{\text{Unavoidable delay}}{\text{Net discharge time}} = \frac{299}{1846} = 16.2\%$$

a 13 percent of 1846 hours = 240 hours.

Nominal Hatch Rate

Table 11 provides the nominal hatch discharge time which evolves when the cargo characteristics projected in Table 4 (less deck cargo) are combined with the commodity discharge rates of Table 9 and the delay projection of 26.5 percent. The gross ST is based upon 1000 MT of ship bale capacity and includes a 30 percent stowage loss. A nominal discharge time of 26.3 hours is required per 1000 MT of ship bale capacity. The average discharge rates which result are:

$$\frac{360.1}{26.3} = 13.7 \text{ Gross ST per hour}$$

$$\frac{333.5}{26.3} = 12.7 \text{ Net ST per hour}$$

TABLE 11

AVERAGE DISCHARGE RATE PER HATCH*

Unit Load	ST Gross Per 1000 MT of Ship Bale Capacity	Number of Drafts	Drafts Per Hour	Hours to Discharge
Containers	64.0	19.1	11.7	1.63
Pallets	113.0	145.6	18.0	8.01
Drums	45.1	27.9	14.3	1.94
General Cargo	106.0	93.8	12.2	7.92
Vehicles	32.0	5.1	4.0	1.26
	360.1			20.76

* Includes 30 percent stowage loss and excludes deck cargo
Nominal Hatch Hours/1000 MT Bale Capacity =
20.76 hours + (unavoidable delay 26.5%) (20.76) = 26.3 Hours

LIGHTER CHARACTERISTICS

The factors affecting ship discharge rate were considered in the previous section. From that discussion, the reader can derive three areas in which lighters may potentially influence the ship discharge rate:

1. Hook cycle time.
2. Unavailability of lighters.
3. Bad weather effec s on loading of lighters.

It is to be noted that for the purposes of this report, the term "lighter" will be used generically to indicate all forms of transport vehicles assigned to move cargo from ship to shore including amphibians, landing craft and helicopters. Identification of waterborne or airborne lighters will generally be by context.

Hook Cycle Time

The potential influence of the lighter on hook cycle time is in connection with the landing of drafts and preparations for return of the hook. Anyone who has observed the discharge of cargo into small lighters is appreciative of the awkwardness of the operation. Once the lighter is secured alongside the ship by mooring lines, the lighter crew awaits receipt of the drafts from directly above. Each draft is swung over the side of the ship and lowered under the observation of a signalman who directs the winchman. When the draft is within reach of the lighter's crew, it must be guided into a suitable position and further lowered until it bottoms on the deck. This operation becomes progressively more difficult as more drafts are loaded and maneuvering space for the crew is diminished. The task of removing slings also becomes more difficult because of space limitations. These events are time consuming and delay the return of the hook to the hold for the next draft.

A question often asked is whether differences in cargo space characteristics of lighters cause any one lighter to be more or less efficient than others,thereby directly influencing ship discharge efficiency. Conclusions reached by ORO (reference 6) based on Pinetree time studies indicate "... that there is no correlation (persistent from cargo to cargo) between lighter type and any of the various mean hook-cycle times." It is further concluded that "... although it is possible that a trend might be detected with additional data, the possibility that such a trend would be an important one appears to be precluded."

Delays Waiting for Lighters

Two types of delays are possible: delays resulting from unavailability of lighters and delays resulting from time lost in maneuvering lighters in and out of mooring position. Unavailability can be overcome by assignment of a sufficient number of lighters to the operation. (This will be quantitatively analyzed in subsequent paragraphs). As a result of time studies of various lighter mooring tests and analysis, ORO (reference 6) concludes that "... lighter maneuvering times are not important as a factor controlling relative lighter performance." The supporting analysis observes that normally the hook cycle is longer than the time for interchange of small lighters. With large lighters the situation is reversed; however, the capacity of these lighters necessitates infrequent interchange. In all cases, the productivity loss is less than 2 percent.

Bad Weather Effects

Swells and waves seriously aggravate the chore of landing drafts, since the lighters cannot be held stable enough to permit accurate placement of drafts. This represents a distinct hazard to the crew. Further, it increases hook cycle time, thereby reducing ship discharge rate. Finally, lighterage operation at decreased capacity per trip reduces the hourly delivery rate of the family of lighters and in turn results in insufficient lighters on hand at the ship.

Numerical Analysis of Lighter Performance

Table 12 provides pertinent characteristics for various lighters currently available. Sources utilized for this data are field manuals (references 24, 28 and 29) and TOE's (references 66, 69 and 73 through 77). Each lighter is analyzed to determine, first, the number of drafts of each cargo commodity which will fit in its cargo space and, next, an average load carried per trip for each lighter based on:

1. Projected cargo mix (see Table 4).

2. Average weight per draft for each commodity (see Table 4).

The results of this analysis are summarized in Table 13. In addition, Table 13 contains estimated speeds at which the lighters are projected to operate in LOTS environment. Some of these speeds were obtained from analysis of NODEX reports (reference 43). The nominal lighter capacities and speed contained in Table 13 assume good sea conditions and must be degraded when considering bad weather operation.

Another analysis was conducted to determine the compatibility of cargo size and weight with existing lighters. Unlike landing craft and BARC's, LARC-V's and helicopters are unsuitable for the transport of most vehicular resupply by virtue of space or weight limitations. Based upon the vehicular supply of three infantry and one armored division, as analyzed in reference 89, 92 percent of the vehicular tonnage (equivalent to 13 percent of the total tonnage) is not

TABLE 12
ESTIMATES OF LIGHTER CARGO-CARRYING CAPABILITIES

Type of Lighter	No. Pallets (40"x48")	No. Nets	No. Drums	No. Vehicles	No. Con-tainers	Average Load (ST)	Avg. Load (Vehicles Only) (ST)[1]	Cargo Space
Amphibians								
LARC-V	4	4	24	0	1	3.8	0	8'8"x16'0"
LARC-XV	12	12	72	1.0	3	11.1	6.3	13'6"x24'0"
BARC	52	40	400	2.5	16	36.8	15.7	14'0"x38'3"
Landing Craft								
LCM-8	42	35	140	2.5	16	32.1	15.7	14'4"x42'0"
LCU	153	126	1260	6.6	51	110.0	41.5	12'6"x96'0" and 25'0"x96'0"
Helicopters								
CH-47	4	4	12	0	1	3.8	0	N/A
H-34	1	1	5	0	0	1.5	0	N/A
UH-1	1	1	3	0	0	1.0	0	N/A

1. Applicable when used only for vehicular transport.

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transportable in LARC-V's. Vehicular transport in LARC-V's is further inhibited by the absence of a discharge ramp, necessitating the lifting of vehicles as the only means of removal. This study, consistent with the results of the Transportation System Study (reference 89), restricts LARC-V's and helicopters to non-vehicular transport, and projects that 74 percent of the vehicular tonnage (equivalent to 10 percent of the total tonnage) cannot be carried in LARC-XV's. Similarly, this study projects that, if required, all vehicles may be transported in landing craft and in BARC's.

TABLE 13
LIGHTER CHARACTERISTICS

Type of Lighter	Average Load (Short Tons)	Average Speed (mph) Water (Air)	Land
Amphibians:			
LARC-V	3.8	8.2	5.0
LARC-XV	11.1	8.0	5.0
BARC	36.8	6.5	N/A[1]
Landing Craft:			
LCM-8	50.0	10.5	N/A
LCU	125.0	8.0	N/A
Helicopters:			
CH-47	3.8	(70.0)	N/A
H-34	1.5	(70.0)	N/A
UH-1	1.0	(70.0)	N/A

[1] Assumed to discharge adjacent to shore.

Lighter Productivity

The nominal productivity of a lighter engaged in LOTS discharge may be defined as:

$$\frac{\text{ST Delivered}}{\text{Hour}} = \frac{\text{Lighter Capacity}}{\text{Time/Round Trip}} = \frac{C}{\frac{2D_l}{r_l} + \frac{2D_w}{r_w} + \frac{C}{d} + \frac{C}{b}}$$

where C = Capacity (ST)

D_l = One-way land distance (miles)

D_w = One-way water (or air) distance (miles)

r_l = Average land speed (mph)

r_w = Average water (or air) speed (mph)

d = Loading rate at ship (ST/Hr.)

b = Discharge rate at shore (ST/Hr.)

Plots are provided in Figures 4, 5 and 6 of lighter productivity vs. representative distances, loading rates and discharge rates. For convenience in plotting and comparing results, an arbitrary lighter productivity index has been established for each lighter type. A summary of the index equivalencies follows in Table 14.

TABLE 14
INDEX EQUIVALENCIES SUMMARY

	Value of Variables When Index = 1				
Lighter Type	D_w (mi)	D_l (mi)	d (ST/Hr)	b (ST/Hr)	Lighter Productivity equivalent to Index 1 (ST/Hr)
Amphibians:					
LARC-V	1	1	13.7	30	3.63
LARC-XV	1	1	13.7	30	6.08
BARC	1	N/A	13.7	30	8.74
Landing Craft:					
LCM-8	1	N/A	13.7	30	8.93
LCU	1	N/A	13.7	30	9.24
Helicopters:					
CH-47	5	N/A	228[1]	228[1]	21.56
H-34	5	N/A	90[1]	90[1]	8.50
UH-1	5	N/A	90[1]	90[1]	5.68

[1] Equivalent to 1 external load/minute.

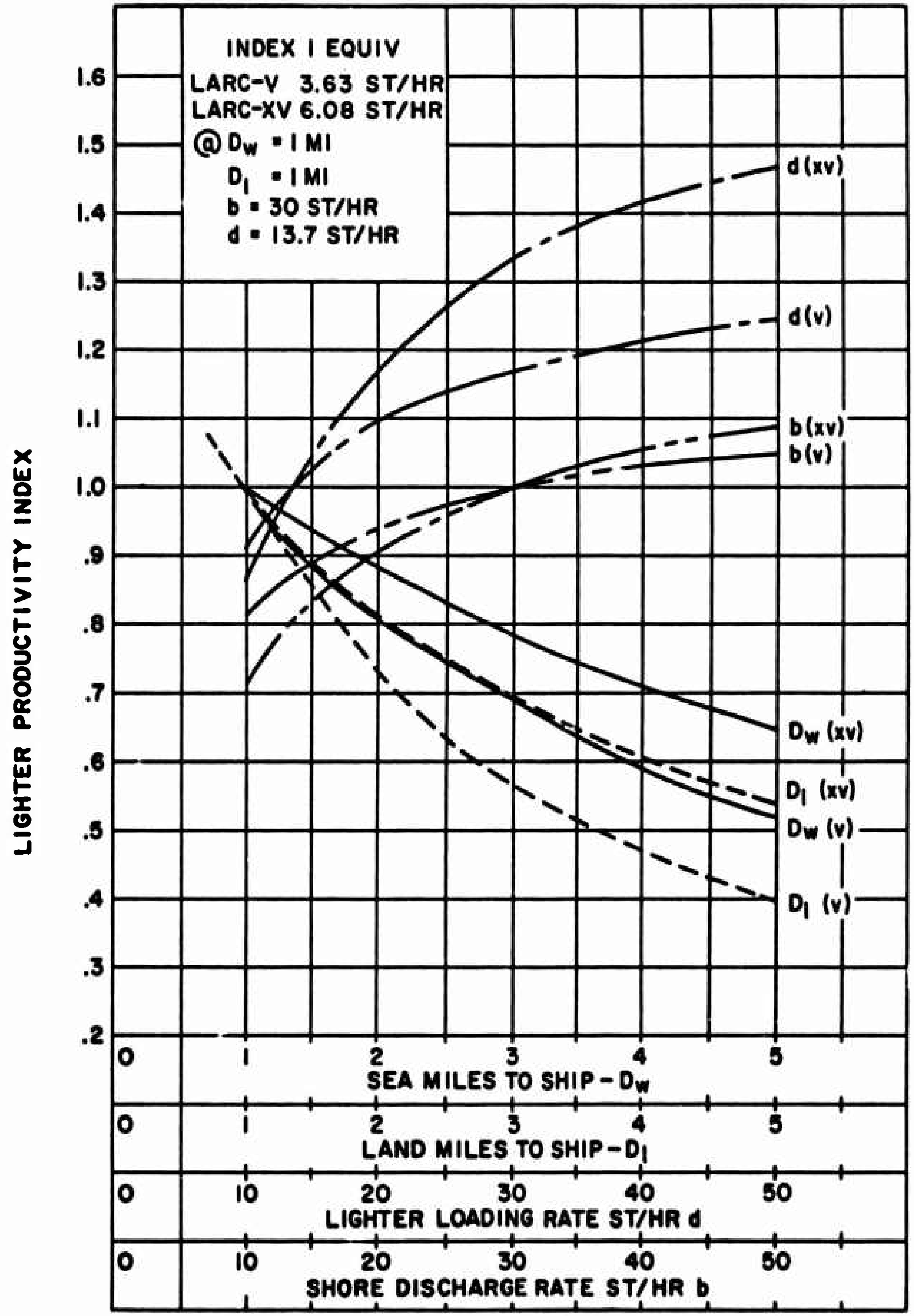

Figure 4. LARC-V and LARC-XV Productivity

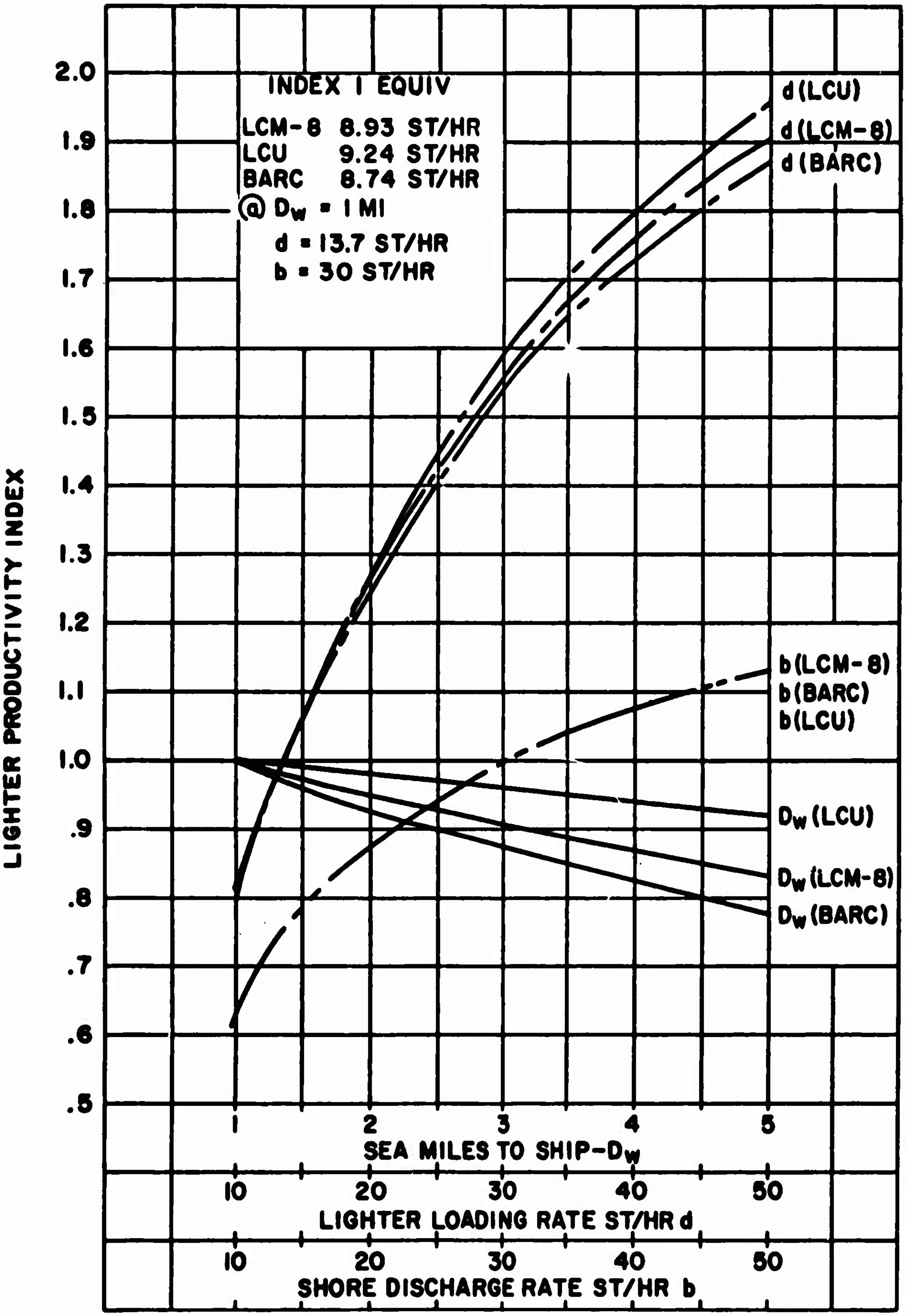

Figure 5. Landing Craft and BARC Productivity

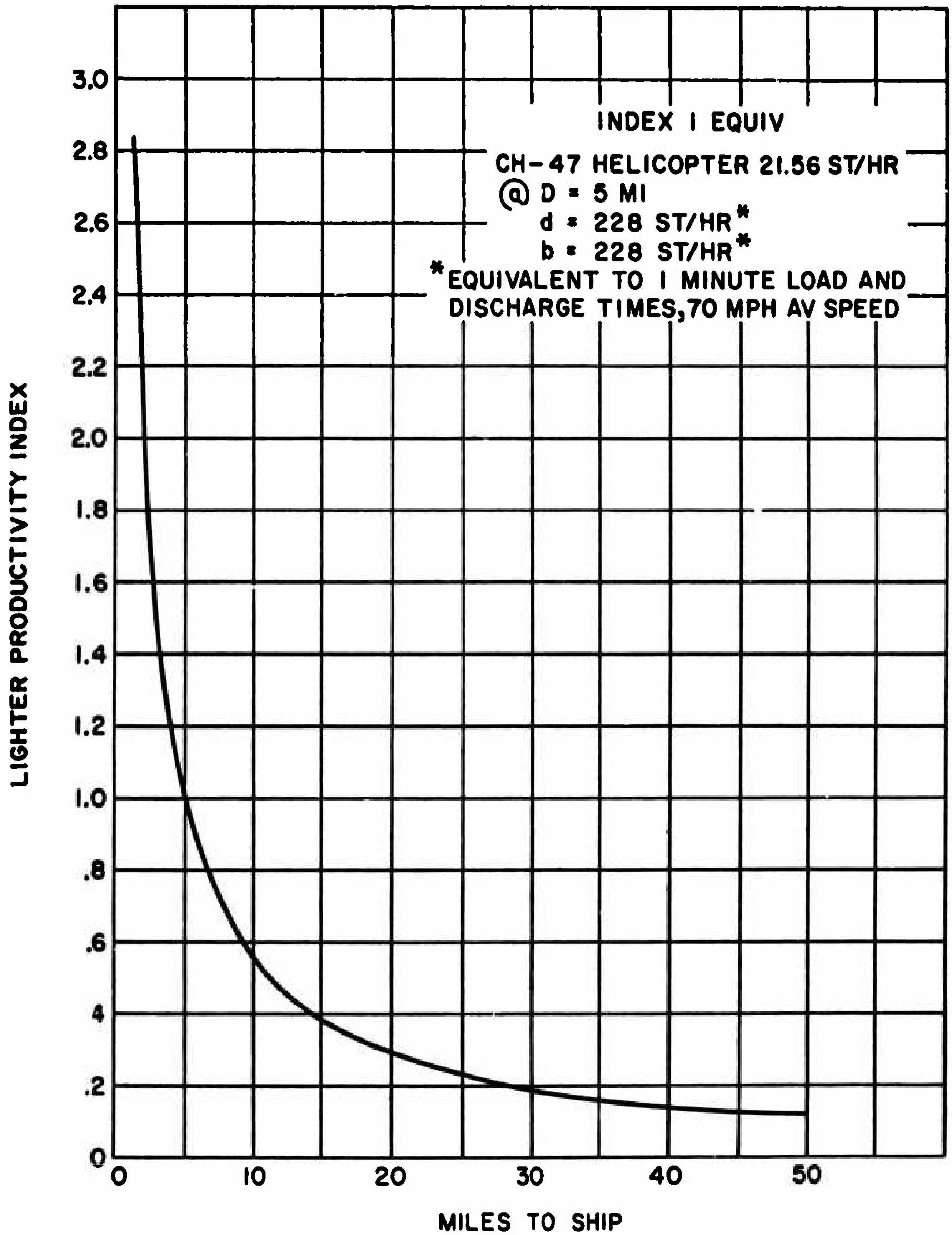

Figure 6. Helicopter Productivity

Availability of Lighters

Existing amphibian, landing craft and helicopter company TOE's are organized on the basis of a planned percentage of the organizational task lighters being available for sustained two-shift-per-day discharge. The unavailable task lighters may be undergoing scheduled maintenance or inoperative. Present availability planning factors are as follows:

Amphibians:	LARC-V	- 0.85	(reference 75)
	LARC-XV	- 0.79	(reference 76)
	BARC	- 0.80	(reference 77)
Landing Craft:	LCM-8	- 0.75	(reference 73)
	LCU	- 0.83	(reference 74)
Helicopters:	All	- 0.25	(reference 66)

It is probable that periods of inactivity between ship arrivals and periods of operational shutdown due to bad weather will afford these organizations the opportunity to perform preventive maintenance. However, it cannot be assumed that malfunctions occur on schedule any more than it can be assumed that weather conditions can be scheduled. Thus it would be unreasonable to assume an improvement in these availability planning factors.

Stringent preventive maintenance requirements on helicopters restrict their planned availability for sustained operation to 25 percent (reference 66). Consistent with this planning factor, this study estimates that each organizational helicopter will be available for LOTS operations five hours a day. Dependent on environmental conditions affecting fuel consumption, each helicopter will land for one or more 10 to 15-minute fueling stops.

Nominal Lighter Requirements

The lighter productivity equation, page 39, may be expanded to permit determination of the nominal number of lighters required to fully sustain a hatch with a discharge rate of h short tons per hour. The total number of lighters required to discharge the entire ship would be equal to the number required to sustain discharge at one hatch multiplied by the number of hatches (n), hence:

Nominal number of lighters per ship

$$= \frac{nh}{A}\left[\frac{2D_l}{r_l C} + \frac{2D_w}{r_w C} + \frac{1}{d} + \frac{1}{b}\right]$$

Nominal vs. Actual Lighter Performance

If all functions pertaining to LOTS were fully automated, allowing no variations from nominal in weight of each cargo draft, loading rate per draft, lighter capacity, lighter speed and discharge rate ashore then a military planner could place full reliance on lighter selections made on the basis of the nominal productivity equations.

However, LOTS operations consist of men and machines performing numerous operations in unstable environments, each subject to random variations and delays. To what extent do these variations degrade nominal performance?

A computer program was developed under this contract which simulates complete LOTS operation performance and affords the user the opportunity to introduce random variations and to measure their effects.

More than 7000 lighter hours of LOTS operation were simulated during which random variations were introduced and their relative and total influence measured.

Random variations were introduced in:

1. Loading time at the ship.
2. Lighter capacity.
3. Travel time to ship, to shore and on land.
4. Discharge time at shore.
5. Occurrence of deadlines.

Lighter and cargo characteristics, ship discharge rates and distances used were consistent with relationships developed previously in this report. In addition, realistic estimates of standard deviations (i.e., measure of variance from nominal) were used in some runs.

Simulation results pertinent to this discussion are summarized below.

1. Random variations in each of the factors 1 through 5 above reduce lighterage productivity below corresponding nominal values. Considered individually or collectively, their contributions to degradation appear to be equivalent. It would require many more simulation hours than time permitted to establish specific values for the small differences between the influence of these factors. Such expenditure appears unwarranted in consideration of the relatively small influence such variations have been found to exert.

2. The influences of number of hatches serviced, of differences between hatch rates on a ship, and of ship distance (0 to 5 miles) impose no additional measurable degradation.

3. The influence of random occurrence of lighters deadlined imposes no additional degradation above that which would result from applying equivalent probabilities of deadline in a calculation of nominal values.

4. Significant hour-to-hour fluctuations in productivity develop for each lighter type. However, the long term effect of random variations on the performance of lighters studied was uniform as described by Figure 7. It is observed that, as the nominal productivity of lighter families approaches the nominal ship discharge rate, degradation increases in lighterage performance. At the point where the two nominal lines intersect, 95 percent of nominal lighter productivity is attainable. An increase in the number of lighters beyond this point brings about only minor improvement in productivity.

<u>Lighterage Weather Degradation</u>

While a great deal of frequency-of-occurrence data on wave heights, as experienced throughout the world, is available, virtually no quantitative data is available on the performance of lighters in heavy seas.

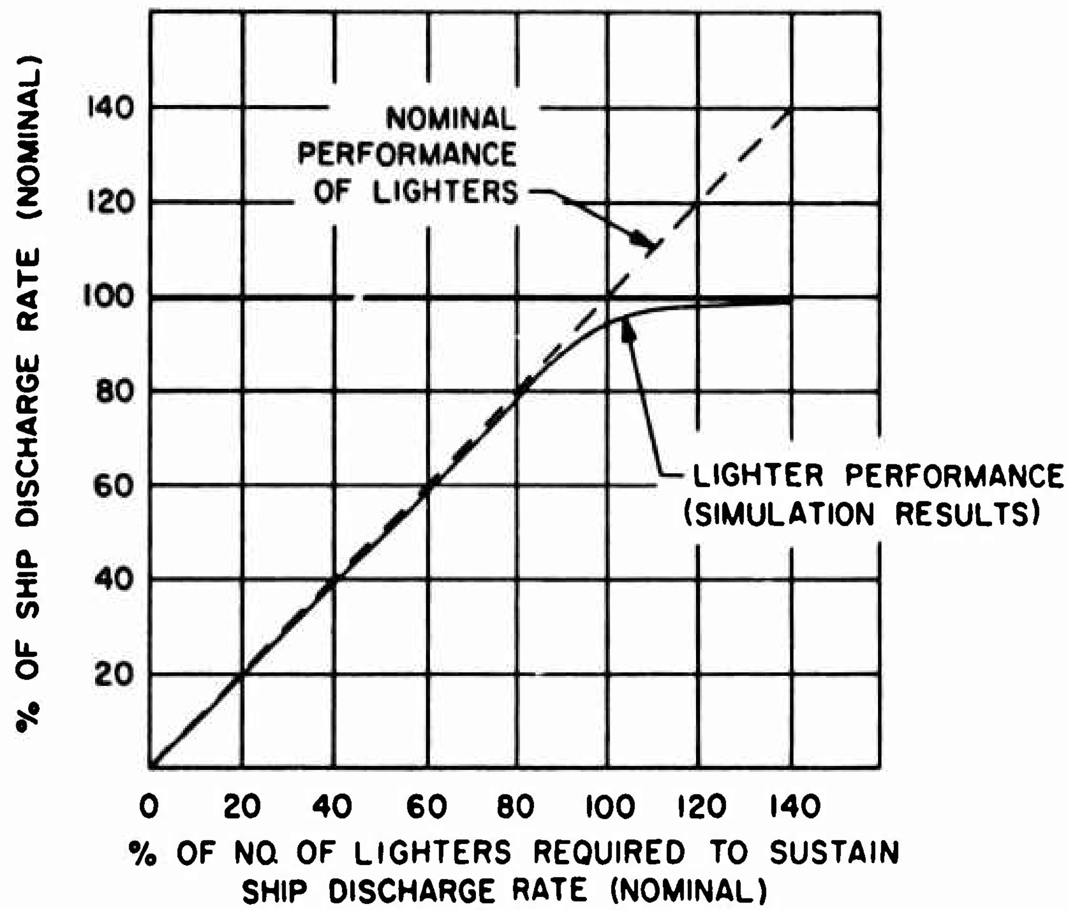

Figure 7. Simulation Results/Lighter Performancy

Several qualitative reports of World War II DUKW operations are republished in an ORO report (reference 6); however, they offer no firm basis for judgements of capability on new amphibians.

It would appear that to permit planning of LOTS resupply operations in specific areas and during specific months, such lighterage degradation information would be imperative.

The influences of weather and bad sea states on discharge are manifold. Below deck, weather can cause cargo to shift and spew as well as preclude the use of forklift trucks. Precipitation requires the use of cumbersome hatch tents. On deck, footing can become dangerous because of icy or wet conditions on the ship and the lighter. Mooring lighters alongside the ship can become hazardous for personnel, the ship, and the lighter because of the vessels' surging together as well as rolling and pitching.

Cargo drafts tend to swing as the ship rolls and, when positioned over the lighter, are difficult to land accurately. Thus lighters will take on less cargo than under good conditions. With the lighter enroute, steering and handling are difficult and speed is reduced.

The above-referenced report estimates relative weather availability of lighters as ranging between 68 percent for a DUKW and LCM-6 to 75 percent for a BARC and 80 percent for a BDL.

This report projects a 75 percent weather availability for the LARC-V, LARC-XV, BARC, LCM-8 and LCU.

In considering helicopter operation, sea state is no longer the prime factor. However, wind conditions and visibility become key factors. Recognizing the increased speed and carrying capability of newer rotary wing craft such as the CH-47 Chinook, a 90 percent weather availability is assumed.

Lighterage Cost of Operations

Table 15 provides cost comparison information for various amphibians and landing craft; sources of the information are identified. Initial cost of equipment is amortized over a three year period in accordance with accepted military practice. Personnel costs are calculated at $14.30 per day consistent with previous reports (references 6 and 88). In deriving Table 16 wherein summary data is given, fuel costs for all waterborne lighters are considered to be $0 09 per gallon.

Daily fuel costs are not solely dependent on the quantity and type of lighters employed, but also depend upon the extent of usage. Regardless of the number of lighters assigned to a discharge site, the mission requirement of 45,000 ST per month dictates the approximate number of trips to be made each month by the lighter group(s). Recognizing that additional fuel is consumed under unfavorable weather conditions, an inefficiency factor of 1.25 is projected in computing daily fuel costs per site.

$$\text{Daily fuel cost} = 1.25\left[\frac{45{,}000\ \text{ST}}{30\ \text{days}}\right] g\left[\frac{2D_w}{C} + \frac{2D_l}{C} + fr_w\left(\frac{1}{d} + \frac{1}{b}\right)\right]$$

In the above equation for sea-going lighters, g is the fuel cost per

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TABLE 15
LIGHTERAGE COST COMPARISON DATA

(1) Lighter	(2) Initial Cost[1] ($)	(3) TO&E Personnel per Lighter	(4) Annual Maintenance Cost % of (2)	(5) Amortization Cost (3 year) (2) / 3 x 365 ($)/day	(6) Maintenance Cost/Day ($)	(7) Personnel Cost/Day $14.30x(3)	(8) Fuel Consumption Gallons per mile
LCM-8	75,800[2]	12.5[3]	14.5[2]	69.22	30.14	178.75	3.50[2]
LCU	527,000[4]	14.2[5]	5.0[4]	481.28	72.19	203.06	6.10[4]
LARC-V	31,000[6]	6.5[7]	10.0[8]	28.30	8.50	92.95	2.08[9]
LARC-XV	82,000[6]	7.1[10]	5.0[8]	75.00	11.22	101.53	4.16[9]
BARC	338,000[6]	13.5[11]	2.0[12]	309.00	18.50	193.05	5.0[9]

1. Initial cost data is used for comparative purposes and does not consider sunk costs.
2. Reference 6.
3. TOE 55 - 128 D.
4. Operations Research Office Report T-316.
5. TOE-55 - 129 D.
6. Current Production Cost.
7. TOE 55-138 E.
8. TRECOM, Marine Division Estimate.
9. Engineering Test Results.
10. TOE 55-139 E.
11. TOE 55-140 E.
12. 554 Transportation Platoon (BARC) Ft. Story.

mile (reference Table 16) and f is the percent of normal fuel consumption while the lighter is loading and unloading. All lighters are assumed to use 20 percent of normal underway consumption while loading at the ship. All lighters with the exception of the BARC which is assumed to shut down its engines, are assumed to use 20 percent of normal underway consumption while discharging at the shore.

TABLE 16
LIGHTERAGE COST SUMMARY

Lighter	Total Daily Cost (Excluding Fuel) $	Fuel Cost $/Mile
LCM-8	278.11	0.315
LCU	756.53	0.549
LARC-V	129.75	0.190
LARC-XV	187.75	0.374
BARC	520.55	0.450

Table 17 provides cost comparison information for several helicopters: the CH-47, the CH-34A and the UH-1B. Preliminary estimates on costs for the CH-47 are taken from "Army Air Logistical Support Study" by Nortronics Division of Northrop Aviation, December 1962.

Data for initial cost of the CH-34 and the UH-1B was taken from a TRECOM estimate, January 1964, and data for operational costs for both helicopters from "Maintenance and Operating Costs of Army Aircraft" - Army Aviation and Surface Material Command, August 1963.

TERMINAL SERVICE

Shore Discharge Operations

The nature of the discharge mission ashore precludes establishment of a singular arrangement of equipment and personnel. Road nets, degree of cargo segregation required, and nature of line-haul each

TABLE 17

HELICOPTER COST COMPARISON DATA

Item		CH-34A	UH-1B	CH-47
1	Initial Cost + 25% spares	$276,000	$330,000	$1,000,000
2	Total cost per flying hour including fuel and direct maintenance	114.45	87.48	160.00
3	Daily flight crew cost			69.00
DAILY COST				
Amortization:				
	Item 1/10 (365)	76.00	90.00	274.00
Operating Cost:				
	Item 2 x 5 hrs.	575.00	437.00	800.00
	Item 3			69.00
	Total Cost/5 Hr. Day	$651.00	$527.00	$1143.00

influence the method of operation. Were it not for these uncertainties, techniques of discharge affording an improved level of efficiency could be formulated. For example, lighterage discharge areas could be segregated by type of commodity, and equipment arrangements could be used which are most compatible with that commodity exclusively (i.e., special A-Frames for pallet lift-out, etc.).

Terminal service companies maintain 92 operational personnel on shore to conduct lighter discharge operations. This is the equivalent of 9.2 men to handle each hatch's discharge per shift. Similarly 6 cranes, 9 rough terrain forklifts and 5 conventional forklifts are available. This is the equivalent of four pieces of appratus per hatch discharged.

In the discharge of amphibians carrying the projected cargo mix, it is unreasonable to assume that this large complement will be required in the future. This study assumes:

1. LARC-V and LARC-XV
   On a per hatch equivalency basis:
   a. 5 operational shore personnel per shift.
   b. 2 items of discharge equipment.

2. Landing Craft and BARC - General Cargo Delivery
   (Two transfers required, one at the shore line and one at the transit area).
   On a per hatch equivalency basis:
   a. 15 operational personnel/per shift.
   b. 6 items of discharge equipment.

3. Landing Craft and BARC - Vehicular Cargo Delivery
   No special equipment is required for roll-off discharge. It is assumed that vehicle drivers will be provided by other transportation units (line-haul).

Estimates on the cost of equipment are provided in Table 18. The existing TOE contains:

$$\frac{\text{92 shore operating personnel}}{\text{136.5 total administrative, maintenance and operating personnel}}$$

or a ratio of 67.5 percent. This same ratio will be used to project shore personnel in this study. Table 19 provides daily shore slot costs.

Hatch Stevedoring Cost

The current terminal service company TOE requires 154 stevedore operational personnel aboard a five hatch ship, or 30.8 men per hatch. These men are supported by a proportionate number of administrative and maintenance personnel ashore, which is estimated at 7.7 men. This study, therefore, assigns 38.5 TOE personnel per hatch at a total daily personnel cost of 38.5 x $14.30 = $550. The daily cost of hand-operated forklifts and handling gear is assumed to be $5. Therefore, the total daily cost per hatch = $555.

TABLE 18
MATERIALS HANDLING EQUIPMENT

(1) Item	(2) Federal Stock Cost	(3) Maintenance Cost[2] (Av. Annual)	(4) Overhaul Cost	(5) Cost/Day (2)+(3)+(4)
Crane				
10T (Crawler)	\$22,600	\$350	\$5196 (3 to 4 yr)	\$8.89[1]
40T (Crawler)	49,354	750	9124 (8 to 10 yr)	12.72[1]
20T (Truck)	28,573	500	8034 (5 yr)	9.51[1]
Forklift				
6,000 lb. (Rough Terrain)	14,097	450	3450 (3 yr)	6.32[1]
10,000 lb. (Rough Terrain)	19,612	600	4900 (3 yr)	7.91[1]
144-inch Lift (Gas)	5,000	350	1000 (1 to 1-1/2 yr)	3.53
4,000 lb. (Hand)	368			1.01[3]

1. 15-Year life assumed.
2. Maintenance cost derived from records kept by the Office of the Director of Maintenance, Army Mobility Support Center.
3. 1-Year life assumed.

TABLE 19

DAILY SHORE SLOT COST FOR GENERAL CARGO DISCHARGE

(Based on 1 Shore Slot per Hatch)

Type Slot	(1) Number of Operating Personnel	(2) Number of Personnel @ 67.5%	(3) Number of Equip-ment	(4) Cost of Equip-ment/ Day*	(5) Cost of Personnel @$14.30/ Day	(6) Total Cost (4)&(5)
LARC-V & LARC-XV	10	14.8	2	$18.00	$212.00	$230.00
Landing Craft & BARC	30	44.5	6	54.00	636.00	690.00

* Based on average daily cost of cranes and forklifts.

DEVELOPMENT OF OPTIMUM LOTS SYSTEMS

In the beginning of this report, the term "LOTS Expenditure Index" was defined as the direct arithmetic addition of monthly personnel and equipment operating and maintenance costs, equipment amortization costs and ship waiting costs while at a LOTS discharge site. Preceding discussions have identified and developed individual costs for ships, lighters, ship discharge personnel and shore personnel. In addition, relationships have been formulated and tested on lighter productivity and its potential influences.

This discussion identifies techniques of organizing LOTS operational equipment and personnel and establishes LEI's for various candidate LOTS systems. Candidate systems are then tested to establish and compare their performance under conditions of weather degradation and dispersed anchorages, thereby permitting determination of optimum candidates. Results of these analyses are further used to identify promising areas of improvement for further investigation.

The approach followed in this discussion consists of four steps:

1. Step 1 — Determination of resulting ship costs for alternate techniques of LOTS organization.

2. Step 2 — Determination of LEI for candidate LOTS systems for alternate techniques of LOTS organization.

3. Step 3 — Analysis to determine most suitable LOTS organization(s) (technique and equipment) in consideration of environment (weather and military situation).

4. Step 4 — Analysis to identify promising areas of improvement for further investigation.

STEP 1 — SHIP COST VS. LOTS ORGANIZATION TECHNIQUE

Previous discussion has established the relationship of ship discharge time to ship cost, based on one, two, and three-ship simultaneous discharge operations. In addition, nominal hatch discharge rates were developed. As projected previously, a reasonable estimate of the nominal discharge rate of each single-rigged hatch (excluding delays resulting from weather effects and unavailability of lighterage) is

13.72 gross short tons per hour and 12.7 net short tons per hour, resulting in an estimated 26.3 working hours to discharge the homogenous cargo content of 1000 measurement tons of ship bale capacity (reference Table 11). Double-rigged hatches from which two lighters are worked simultaneously are estimated to discharge at a rate of 160 percent of the equivalent single-rig rate.

Computer simulation has established that random variations in performance reduce predicted hatch rates to 95 percent of the above nominal values. This discussion establishes comparisons between the method of operation aboard each ship (i.e., number of hatch gangs and lighter mooring locations) and ship cost chargeable to LOTS operations.

The influence of numbers of hatch gangs varies with the characteristics of the ship being discharged. A five-hatch ship with only single rigging will not discharge any faster by utilizing more than five gangs. However, if one hatch were double-rigged, then a second gang could be put to work, thereby increasing the rate of discharge of that hatch. However, ships contain holds of various sizes, as discussed previously, and discharge may be completed in other holds long before the longest hold is emptied. The ship must wait at anchor to complete the operation. Consider a five-hatch ship with its longest hatch double rigged. If five gangs were used, completion of discharge of the shortest hatch will permit that gang to join the gang already working the longest hatch in order to speed up discharge.

An analysis has been made to determine the possible influence of 5-, 6-, 7- and 8-gang operations on those ships likely to participate in resupply delivery in the event of war. The analysis takes into consideration characteristics of the ship and of the projected prestow and discharge rates. It assumes homogenous cargo prestow conforming to the composition projected in this report. A sample solution is provided here to illustrate the manner of analysis. Results of the analysis are summarized in Table 20.

Example: Determine time required to discharge a C-2 ship with five hatch gangs (Figure 8). Table 11 previously established that 26.3 hours are required for the discharge of 1000 MT of ship bale capacity.

TABLE 20
SHIP DISCHARGE TIME

Type of Ship	Number of Gangs	Time (Hrs.) Utilizing Double Rigging Where Possible	Time (Hrs.) Utilizing Only Single Rigging
C1	5	98.0	98.0
	6	98.0	98.0
	7	98.0	98.0
	8	98.0	98.0
C2	5	101.0	111.9
	6	85.5	111.9
	7	81.7	111.9
	8	71.3	111.9
C3	5	140.3	162.5
	6	113.0	162.5
	7	110.0	162.5
	8	102.5	162.5
Victory	5	87.0	115.5
	6	73.2	115.5
	7	73.2	115.5
	8	73.2	115.5
Liberty	5	115.0	115.0
	6	115.0	115.0
	7	115.0	115.0
	8	115.0	115.0
Mariner	5	135.0	136.8
	6	113.1	136.8
	7	101.5	136.8
	8	93.6	136.8
Challenger	5	113.5	159.7
	6	104.2	159.7
	7	95.4	159.7
	8	81.7	159.7

$$\frac{(24\ \text{hr/day})\ (26.3\ \text{hrs})}{(20\ \text{working hrs/day})\ (.95\ \text{lighter efficiency})} =$$ 33.24 hrs single-rig discharge time/1000 MT bale capacity and 20.76 hrs double-rig discharge time/1000 MT bale capacity

Hatch opening and initial rigging time = 0.5 hr. (estimated).

44 ST/hatch vehicular deck cargo discharge time = 2.0 hrs. (estimated).

Were the ship's double-rigging capabilities not utilized, time for discharge would equal

$$2.5\ \text{hrs} + 3290\ \text{MT}\ \left(\frac{33.24\ \text{hrs}}{1000\ \text{MT}}\right) = 111.9\ \text{hrs}.$$

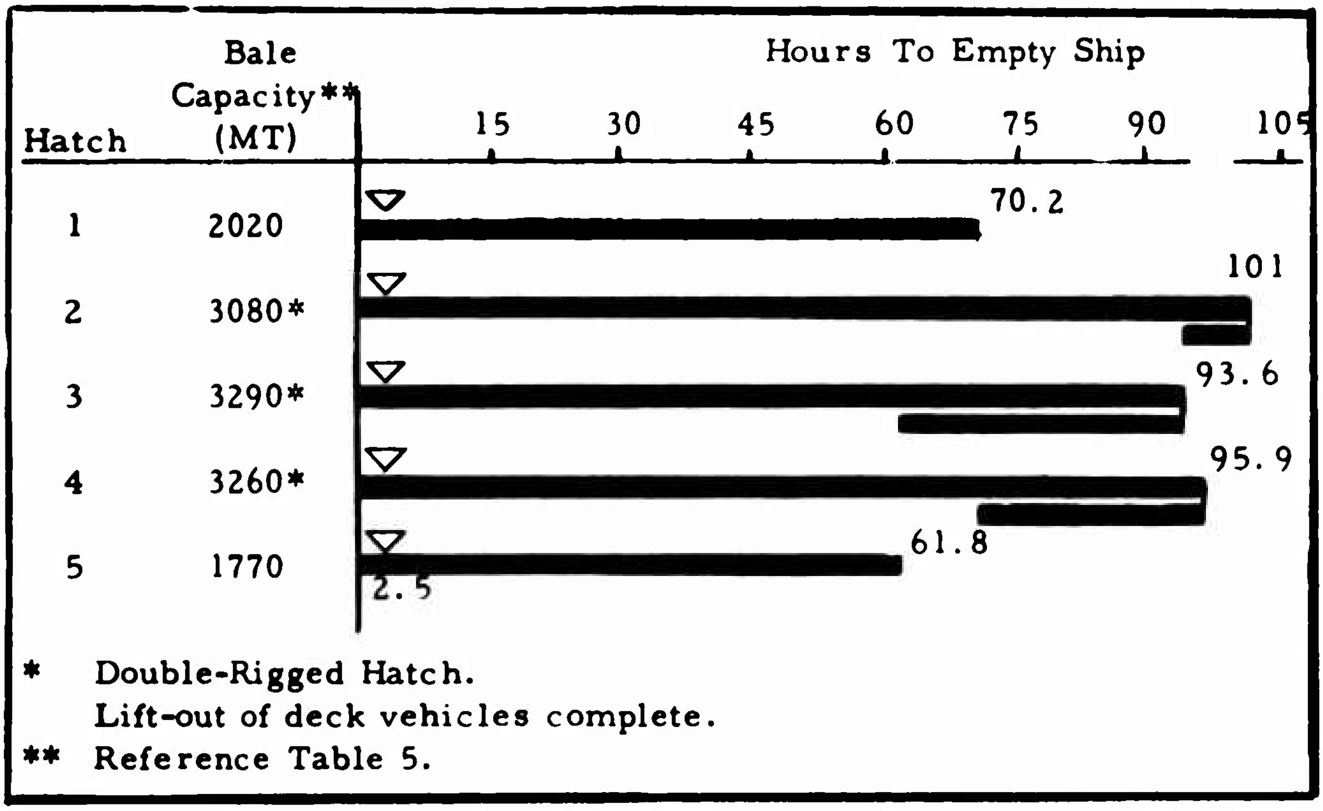

Figure 8. Discharge Operation — C-2

From Table 20, average ship discharge times are calculated for 5-, 6-, 7-, and 8 gang double-rig operations based upon the number of ships of each type available for use in LOTS wartime operations.

These averages are shown below.

Number of Gangs	Average Discharge Hours
5	112.0
6	95.6
7	92.0
8	85.4

Figure 3, which provides plots of ship cost vs. discharge hours is then used to determine the resulting ship cost for 5-, 6-, 7-, and 8-gang operations (see Figure 9). These costs will be combined with LOTS equipment and personnel costs of candidate systems in order to derive LEI's.

STEP 2 – DETERMINATION OF CANDIDATE SYSTEM LEI'S

Having established suitable alternate means of employing LOTS organizations and thereby having determined the resulting ship costs, a determination is made of the quantities and cost of LOTS equipment and personnel necessary to satisfy these organizational arrangements and the over-all mission requirements.

LOTS Equipment Cost

Lighter – The number of task lighters required to sustain discharge at a site is expressed as:

$$N = \frac{nh}{A}\left(\frac{2D_l}{r_l C_l} + \frac{2D_w}{r_w C_w} + \frac{1}{d} + \frac{1}{b}\right) \qquad (1)$$

In the above equation, n reflects the total number of hatch gangs, thus for example: for a two ship-discharge group, six gang operation, n equals twelve.

In the case of candidate families of LARC-V's, LARC-XV's and CH-47 helicopters, supplemental large lighters must be available to provide the capability of transporting heavy lifts. A sufficient number of large lighters is assigned to provide the capability for sustaining vehicular discharge from a minimum of one hatch. This requirement affords flexibility for random occurrence of simultaneous heavy lifts from more than one hatch or one ship. The number of supplemental lighters required is expressed as:

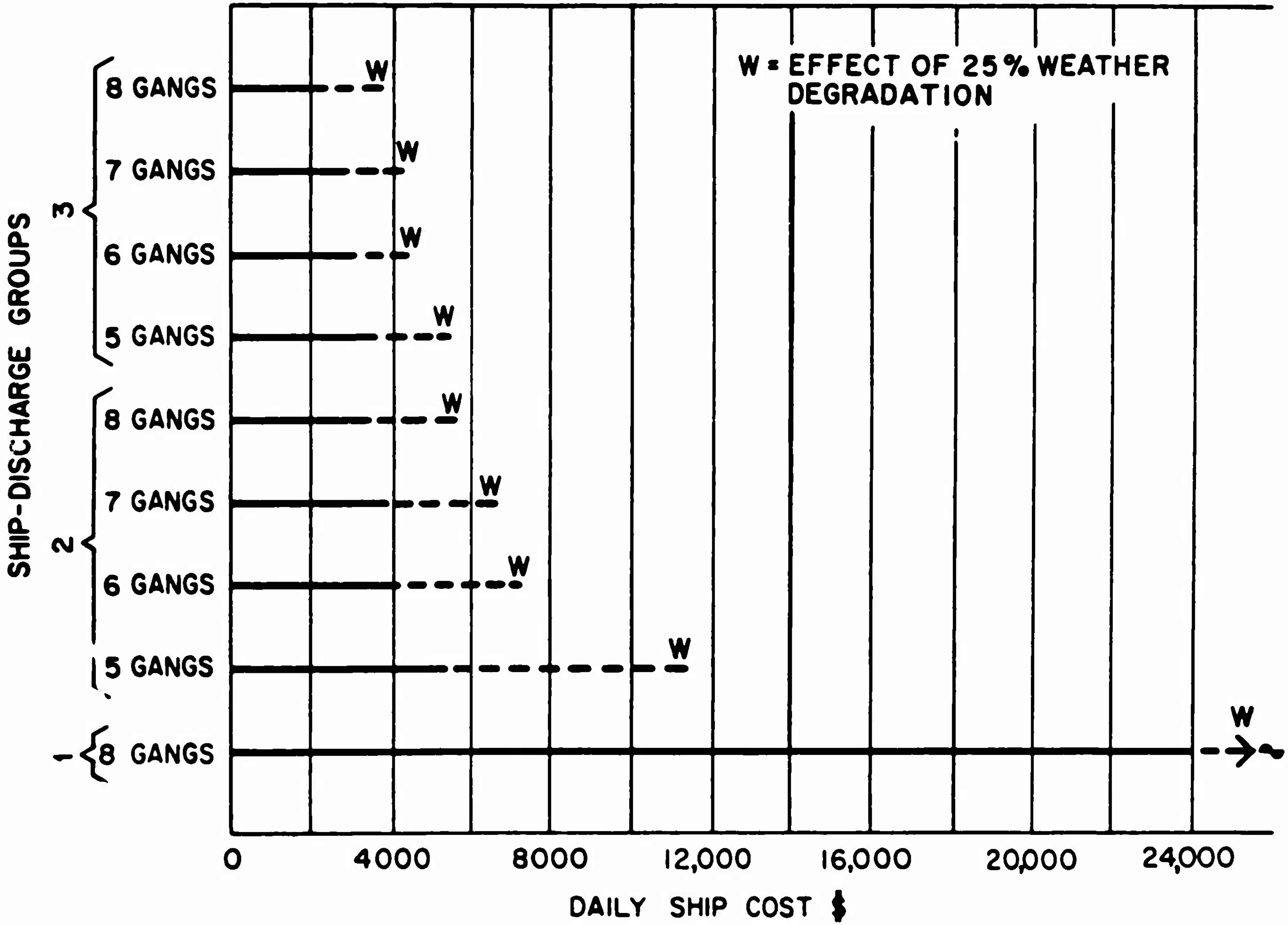

Figure 9. Hatch Gangs vs. Daily Ship Costs

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$$N_s = \frac{h_v}{A}\left(\frac{2D_w}{r_w C_v} + \frac{1}{d_v} + \frac{1}{b_v}\right) \qquad (2)$$

The resulting daily lighterage cost is:

$$\text{Lighter Cost/day} = L_p N_p + L_s N_s \qquad (3)$$

L_p and L_s are the summations of the daily amortization and maintenance costs per primary and supplemental lighter. (See Table 15).

Fuel — The daily fuel cost may be determined from:

$$\text{fuel cost/day} = 1.25(1500)(1-P)\left[g_p\left(\frac{2D_w}{C} + \frac{2D_l}{C} + fr_w\left(\frac{1}{d} + \frac{1}{b}\right)\right]$$

$$+1.25(1500)(P)\left[g_s\left(\frac{2D_w}{C_v} + fr_w\left(\frac{1}{d_v} + \frac{1}{b_v}\right)\right] \qquad (4)$$

The term P in equation (4) represents the percentage of monthly resupply tonnage transported on supplemental lighters.

Hatch Equipment (Reference page 52).

$$\text{Hatch equipment cost/day} = n\,k_1 \qquad (5)$$

Shore Equipment (Reference Table 19)

$$\text{Shore equipment cost/day} = n\,k_2 \qquad (6)$$

Total Equipment cost/day $= \Sigma\ (3)+(4)+(5)+(6)$ (7)

LOTS Personnel Cost

Lighterage Personnel

$$\text{Total Lighterage Personnel} = T_p N_p + T_s N_s \qquad (8)$$

T_p and T_s are the TOE personnel per task lighter as listed in Table 15.

Ship Personnel (Reference page 52)

$$\text{Total Ship Personnel} = n\ k_3 \qquad (9)$$

Shore Personnel (Reference Table 19)

$$\text{Total Shore Personnel} = n\ k_4 \qquad (10)$$

Total Personnel cost/day = $\$14.30\ \Sigma\ (8)+(9)+(10)$ (11)

The LEI for a candidate system may therefore be expressed as:

LEI = Σ (7)+(11)+(appropriate ship cost from Figures 3 and 9)

LOTS System Candidates

The following representative LOTS system candidates have been analyzed to determine their resulting LEI:

a. LARC-V's and supplemental BARC's.

b. LARC-V's and supplemental LCM-8's.

c. LARC-XV's and supplemental BARC's.

d. LARC-XV's and supplemental LCM-8's.

e. BARC's.

f. LCM-8's.

g. LCU's.

h. CH-47's and supplemental BARC's.

Constants used in equations (1) through (11) to derive these LEI's were projected in previous sections of this report, and are summarized in Table 21. Table 22 provides tabular results of the analyses for various organizational arrangements.

TABLE 21
SUMMARY OF CONSTANTS

	LARC-V	LARC-XV	BARC	LCM-8	LCU	CH-47
r_1 (MPH)	5	5	N/A	N/A	N/A	∞
r_w (MPH)	8.2	8.0	6.5	10.5	8	70
d (ST/Hr)	13.72	13.72	13.72	13.72	13.72	228
d_v (ST/Hr)	N/A	N/A	25.4	25.4	25.4	N/A
b (ST/Hr)	30	30	30	30	30	228
b_v (ST/Hr)	N/A	N/A	75	75	75	N/A
C (ST)	3.8	11.1	36.8	32.1	110	3.8
C_v (ST)	N/A	N/A	15.7	15.7	41.5	N/A
P	.12	.10	0	0	0	0.12
A	0.85	0.79	0.8	0.75	0.833	.25
h (ST/Hr)	13.72	13.72	13.72	13.72	13.72	13.72
h_v (ST/Hr)	N/A	N/A	25.4	25.4	25.4	N/A
L ($/Day)	36.80	86.22	327.50	99.36	553.47	1143
T	6.5	7.1	13.5	12.5	14.2	N/A
K_1 ($/Day)	5	5	5	5	5	Note 1
K_2 ($/Day)	18	18	54	54	54	Note 1
K_3	38.5	38.5	38.5	38.5	38.5	N/A
K_4	14.8	14.8	44.5	44.5	44.5	N/A
f	0.20	0.20	0.10	0.20	0.20	N/A
g ($/Mi.)	0.19	0.374	0.45	0.315	0.549	Note 1

Note 1 - Included in L

TABLE 22
ANALYSIS OF NORMAL LEI'S FOR LOTS SYSTEM CANDIDATES

(1) Arrangement Disch. Groups	Hatch Gangs	(2) Water Distance Miles	(3) Number of Lighters Prime	Suppl.	(4) Number of Personnel Lighter	Ship	Shore	(5) Equip. Cost $x1000	(6) Personnel Cost $x1000	(7) Ship Cost $x1000	(8) LEI (5)+(6)+(7) $x1000
Candidate a. LARC-V + Supplemental BARC											
1	8	1	36	3	275	308	118	2.95	10.02	24.00	36.97
1	8	3	52	4	398	308	118	4.27	11.78	24.00	40.05
2	5	1	44	3	327	385	148	3.28	12.30	5.40	20.98
2	5	3	66	4	482	385	148	4.82	14.51	5.40	24.73
2	6	1	54	3	391	462	178	3.70	14.74	4.05	22.49
2	6	3	78	4	561	462	178	5.31	17.17	4.05	26.53
2	7	1	62	3	444	539	207	4.03	17.01	3.75	24.79
2	7	3	92	4	652	539	207	5.88	19.99	3.75	29.62
2	8	1	72	3	509	616	237	4.45	19.47	3.33	27.25
2	8	3	104	4	729	616	237	6.36	22.62	3.33	32.31
3	5	1	66	3	469	577	222	4.21	18.12	3.60	25.93
3	5	3	99	4	698	577	222	6.16	21.41	3.60	31.17
3	6	1	81	3	567	693	267	4.83	21.84	3.00	29.67
3	6	3	117	4	828	693	267	7.21	25.58	3.00	35.79
Candidate b. LARC-V + Supplemental LCM-8											
1	8	1	36	3	274	308	118	2.26	10.00	24.00	36.26
1	8	3	52	3	382	308	118	3.25	11.55	24.00	38.80
2	5	1	44	3	324	385	148	2.60	12.25	5.40	20.25
2	5	3	66	3	466	385	148	3.80	14.28	5.40	23.48
2	6	1	54	3	388	462	178	3.02	14.69	4.05	21.76

TABLE 22 (CONTINUED
ANALYSIS OF NORMAL LEI'S FOR LOTS SYSTEM CANDIDATES

(1) Arrangement Disch. Groups	Hatch Gangs	(2) Water Distance Miles	(3) Number of Lighters Prime	Suppl.	(4) Number of Personnel Lighter	Ship	Shore	(5) Equip. Cost $x1000	(6) Personnel Cost $x1000	(7) Ship Cost $x1000	(8) LEI (5)+(6)+(7) $x1000
Candidate b. LARC-V + Supplemental LCM-8 (Continued)											
2	6	3	78	3	545	462	178	4.29	16.94	4.05	25.28
2	7	1	62	3	440	539	207	3.35	16.97	3.75	24.07
2	7	3	92	3	636	539	207	4.86	19.76	3.75	28.37
2	8	1	72	3	506	616	237	3.77	19.43	3.33	26.53
2	8	3	104	4	725	616	237	5.44	22.56	3.33	31.33
3	5	1	66	3	466	577	222	3.52	18.08	3.60	25.20
3	5	3	99	4	690	577	222	5.24	21.29	3.60	30.13
3	6	1	81	3	564	693	267	4.13	21.79	3.00	28.92
3	6	3	117	4	810	693	267	5.96	25.31	3.00	34.27
Candidate c. LARC-XV + Supplemental BARC											
1	8	1	23	3	204	308	118	3.54	9.01	24.00	36.55
1	8	3	30	4	267	308	118	4.74	9.91	24.00	38.65
2	5	1	30	3	254	385	148	4.18	11.25	5.40	20.83
2	5	3	38	4	324	385	148	5.48	12.26	5.40	23.14
2	6	1	36	3	297	462	178	4.75	13.40	4.05	22.20
2	6	3	44	4	367	462	178	6.04	14.40	4.05	24.49
2	7	1	42	3	339	539	207	5.31	15.52	3.75	24.58
2	7	3	52	4	424	539	207	6.77	16.73	3.75	27.25
2	8	1	46	3	367	616	237	5.70	17.45	3.33	26.48
2	8	3	60	4	480	616	237	7.51	19.06	3.33	29.00

TABLE 22 (CONTINUED)
ANALYSIS OF NORMAL LEI'S FOR LOTS SYSTEM CANDIDATES

(1) Arrangement Disch. Groups	(1) Arrangement Hatch Gangs	(2) Water Distance Miles	(3) Number of Lighters Prime	(3) Number of Lighters Suppl.	(4) Number of Personnel Lighter	(4) Number of Personnel Ship	(4) Number of Personnel Shore	(5) Equip. Cost $x1000	(6) Personnel Cost $x1000	(7) Ship Cost $x1000	(8) LEI (5)+(6)+(7) $x1000
Candidate c. LARC-XV + Supplemental BARC (Continued)											
3	5	1	45	3	360	577	222	5.59	16.57	3.60	25.76
3	5	3	57	4	459	577	222	7.23	17.99	3.60	28.82
3	6	1	54	3	424	693	267	6.44	19.79	3.00	29.23
3	6	3	66	4	523	693	267	8.07	21.21	3.00	32.28
Candidate d. LARC-XV + Supplemental LCM-8											
1	8	1	23	3	201	308	118	2.85	8.97	24.00	35.82
1	8	3	30	3	251	308	118	3.72	9.68	24.00	37.40
2	5	1	30	3	251	385	148	3.50	11.21	5.40	20.11
2	5	3	38	3	308	385	148	4.46	12.03	5.40	21.89
2	6	1	36	3	294	462	178	4.06	13.36	4.05	21.47
2	6	3	44	3	350	462	178	5.02	14.16	4.05	23.23
2	7	1	42	3	336	539	207	4.70	15.47	3.75	23.92
2	7	3	52	3	407	539	207	5.76	16.49	3.75	26.00
2	8	1	46	3	365	616	237	5.02	17.42	3.33	25.77
2	8	3	60	3	464	616	237	6.49	1[illegible].83	3.33	28.65
3	5	1	45	3	357	577	222	4.91	16.53	3.60	25.04
3	5	3	57	3	443	577	222	6.21	17.76	3.60	27.57
3	6	1	54	3	421	693	267	5.75	19.75	3.00	28.50
3	6	3	66	3	507	693	267	7.06	20.98	3.00	31.04

TABLE 22 (CONTINUED)
ANALYSIS OF NORMAL LEI'S FOR LOTS SYSTEM CANDIDATES

(1) Arrangement Disch. Groups	(1) Arrangement Hatch Gangs	(2) Water Distance Miles	(3) Number of Lighters Prime	(3) Number of Lighters Suppl.	(4) Number of Personnel Lighter	(4) Number of Personnel Ship	(4) Number of Personnel Shore	(5) Equip. Cost $x1000	(6) Personnel Cost $x1000	(7) Ship Cost $x1000	(8) LEI (5)+(6)+(7) $x1000
Candidate e. BARC											
1	8	1	16	0	216	308	356	5.82	12.58	24.00	42.40
1	8	3	18	0	243	308	356	6.56	12.97	24.00	43.53
2	5	1	20	0	270	385	445	7.24	15.73	5.40	28.37
2	5	3	24	0	324	385	445	8.64	16.50	5.40	30.54
2	6	1	24	0	324	462	534	8.67	18.88	4.05	31.60
2	6	3	28	0	378	462	534	10.07	19.65	4.05	33.77
2	7	1	28	0	378	539	623	10.10	22.02	3.75	35.87
2	7	3	32	0	432	539	623	11.50	22.79	3.75	38.04
2	8	1	32	0	432	616	712	11.52	25.17	3.33	40.02
2	8	3	36	0	486	616	712	12.92	25.94	3.33	42.19
3	5	1	30	0	405	577	668	10.81	23.60	3.60	38.01
3	5	3	36	0	486	577	668	12.87	24.75	3.60	41.22
3	6	1	36	0	486	693	801	12.96	28.31	3.00	44.27
3	6	3	42	0	567	693	801	15.01	29.47	3.00	47.48
Candidate f. LCM-8											
1	8	1	17	0	213	308	356	2.33	12.54	24.00	38.87
1	8	3	19	0	238	308	356	2.60	12.90	24.00	39.50
2	5	1	22	0	275	385	445	2.94	15.80	5.40	24.14
2	5	3	24	0	300	385	445	3.22	16.16	5.40	24.78
2	6	1	26	0	325	462	534	3.46	18.89	4.05	26.40

TABLE 22 (CONTINUED)
ANALYSIS OF NORMAL LEI'S FOR LOTS SYSTEM CANDIDATES

(1) Arrangement Disch. Groups	(1) Arrangement Hatch Gangs	(2) Water Distance Miles	(3) Number of Lighters Prime	(3) Number of Lighters Suppl.	(4) Number of Personnel Lighter	(4) Number of Personnel Ship	(4) Number of Personnel Shore	(5) Equip. Cost $x1000	(6) Personnel Cost $x1000	(7) Ship Cost $x1000	(8) LEI (5)+(6)+(7) $x1000
Candidate f. LCM-8 (Continued)											
2	6	3	28	0	350	462	534	3.73	19.25	4.05	27.03
2	7	1	30	0	375	539	623	3.98	21.98	3.75	29.70
2	7	3	32	0	400	539	623	4.25	22.34	3.75	30.34
2	8	1	34	0	425	616	712	4.49	25.07	3.33	32.89
2	8	3	38	0	475	616	712	4.96	25.78	3.33	34.07
3	5	1	33	0	413	577	668	4.33	23.71	3.60	31.64
3	5	3	36	0	450	577	668	4.70	24.24	3.60	32.54
3	6	1	39	0	488	693	801	5.10	28.34	3.00	36.44
3	6	3	42	0	525	693	801	5.48	28.87	3.00	37.35
Candidate g. LCU											
1	8	1	15	0	213	308	356	8.97	12.54	24.00	45.51
1	8	3	15	0	213	308	356	9.00	12.54	24.00	45.54
2	5	1	18	0	256	385	445	10.75	15.53	5.40	31.68
2	5	3	20	0	284	385	445	11.89	15.93	5.40	33.22
2	6	1	22	0	313	462	534	13.08	18.72	4.05	35.85
2	6	3	24	0	341	462	534	14.22	19.12	4.05	37.39
2	7	1	26	0	370	539	623	15.41	21.91	3.75	41.07
2	7	3	28	0	398	539	623	16.55	22.31	3.75	42.61
2	8	1	30	0	426	616	712	17.74	25.08	3.33	46.15
2	8	3	30	0	426	616	712	17.78	25.08	3.33	46.19

TABLE 22 (CONTINUED)
ANALYSIS OF NORMAL LEI'S FOR LOTS SYSTEM CANDIDATES

(1) Arrangement		(2) Water	(3) Number of		(4) Number of			(5) Equip.	(6) Personnel	(7) Ship	(8) LEI
Disch.	Hatch	Distance	Lighters		Personnel			Cost	Cost	Cost	(5)+(6)+(7)
Groups	Gangs	Miles	Prime	Suppl.	Lighter	Ship	Shore	$x1000	$x1000	$x1000	$x1000
Candidate g. LCU (Continued)											
3	5	1	27	0	384	577	668	16.02	23.29	3.60	42.91
3	5	3	30	0	426	577	668	17.72	23.90	3.60	45.22
3	6	1	33	0	469	693	801	19.52	28.07	3.00	50.59
3	6	3	36	0	512	693	801	21.22	28.68	3.00	52.90
Candidate h. CH-47 + Supplemental BARC											
1	8	1	11	3	41*	360	59	13.82	6.58	24.00	44.40
1	8	3	17	4	54*	360	59	21.04	6.76	24.00	51.80
2	5	1	14	3	41*	480	74	17.50	8.51	5.40	31.41
2	5	3	22		54*	480	74	27.00	8.69	5.40	41.09
2	6	1	16	3	41*	560	89	19.79	9.87	4.05	33.71
2	6	3	26	4	54*	560	89	31.58	10.05	4.05	45.68
2	7	1	18	3	41*	640	104	22.07	12.26	3.75	38.08
2	7	3	30	4	54*	640	104	36.15	11.41	3.75	51.31
2	8	1	22	3	41*	720	119	26.65	12.58	3.33	42.56
2	8	3	34	4	54*	720	119	40.72	12.77	3.33	56.82
3	5	1	21	3	41*	720	111	25.75	12.47	3.60	41.82
3	5	3	33	5	54*	720	111	39.83	12.66	3.60	56.09
3	6	1	24	3	41*	840	134	29.18	14.51	3.00	46.69
3	6	3	39	4	68*	840	134	47.01	14.90	3.00	64.91

* CH-47 Personnel not included. However, CH-47 Personnel Costs are included in Equipment Cost.

STEP 3 – DETERMINATION OF MOST SUITABLE LOTS ORGANIZATIONS

In the last column of Table 22 is listed an LEI for each LOTS candidate system for various organizational arrangements. These LEI's are for normal operation only (good weather conditions), and do not include weather degradation effects. It is to be observed that for each candidate, the arrangement yielding minimum LEI consists of two ship-discharge groups of five hatch gangs each.

Before attempting to establish preference for any one candidate system, or final selection of the organizational arrangement, it is necessary to consider the degradation effects of bad weather and anchorage dispersion distance.

Weather Degradation

The degrading influence of bad weather on system performance has been discussed previously in this report. When bad weather conditions are encountered which would require a complete stoppage of operations and reduce monthly capability to 75 percent or which would reduce hatch discharge rates to 75 percent of their nominal monthly average, then the resulting average ship discharge times for 5- through 8-hatch gang operations would increase by a factor of $\frac{4}{3}$. The resulting ship cost for each organizational arrangement will increase as previously derived by use of Figure 3 and depicted in Figure 9.

Distance Degradation

LOTS candidate systems may be organized to specifically accommodate anchorages at any reasonable distance. The resulting LEI's for systems designed for a three-mile anchorage are shown in Table 22.

These systems require more lighters (and total lighter personnel) than systems designed for a one-mile anchorage by virtue of the increased travel times required for the three-mile operation. Ship costs, as well as ship and shore personnel costs remain unchanged from the equivalent one-mile system values.

An alternate means of accommodating three-mile anchorages is to commit a system designed for one-mile operation to three-mile operation. When a one-mile system is used in this manner, the resulting degradation in average ship discharge time may be calculated using equation (1). By solving this equation ͵r h when N equals the number of lighters specified for one-mile operation, and D_w equals three miles, the resulting hourly hatch rate is obtained. Then Degraded Ship Discharge Time equals:

$$\frac{\text{Nominal hatch rate}}{\text{Resulting hourly hatch rate}} \times \text{Average Ship Discharge Time}$$

Using Figure 3, a revised ship cost can be obtained. The revised ship cost when added to one-mile lighter, equipment and personnel costs and three-mile fuel costs result in increased LEI's.

Results of Weather and Distance Degradation Tests

Table 23 provides th LEI's which result when the LOTS system candidates are tested for weather and distance degradation. The LEI's are next plotted in Figure 10. It should be noted that although five-hatch gang/two ship-discharge group arrangements provide the least LEI for nominal operation, six-hatch gang/two ship-discharge group arrangements result in lowest LEI's when weather degradation is considered. Candidates e, g and h are the exceptions to this rule. Similarly, when considering distance degradation, three-mile, five-hatch gang/two ship-discharge group systems generally provide least LEI's.

Table 24 summarizes the most efficient arrangements of the various candidates. Where several arrangements are shown for a candidate, one arrangement provides least LEI considering weather effects and the other provides least LEI considering dispersed anchorages.

The following observations are applicable:

1. Candidate systems a through d have least LEI's. Further, they have nominal and weather LEI's within five percent of one another. These systems should be considered equally desirable for one mile discharge operations. However, for three-mile operation, candidates c and d are slightly more desirable than candidates a and b (8 percent lower LEI's).

TABLE 23
ANALYSIS OF WEATHER AND DISTANCE DEGRADATION
LEI'S FOR LOTS SYSTEM CANDIDATES

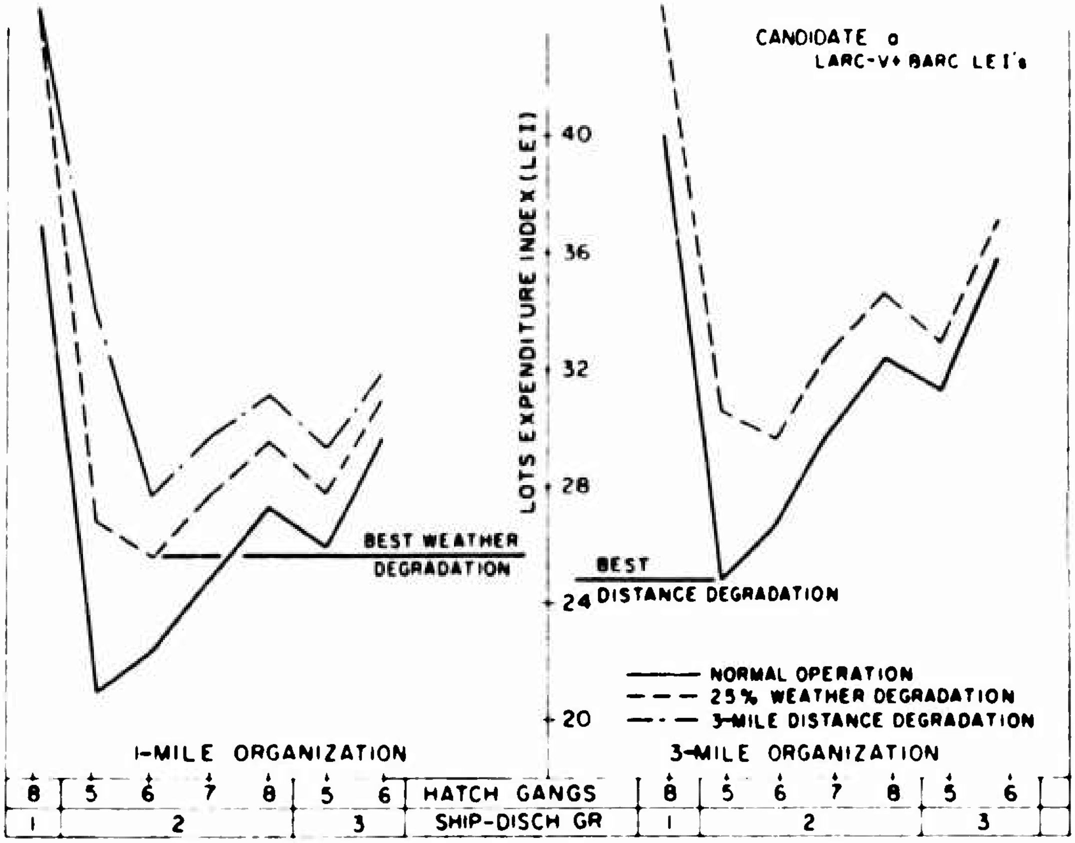
Arrangement		1-Mile Organization			3-Mile Organization	
Ship Disch. Groups	Hatch Gangs	LEI Normal $x1000	LEI Weather $x1000	LEI Distance $x1000	LEI Normal $x1000	LEI Weather $x1000
Candidate a. LARC-V + Supplemental BARC						
1	8	36.97	∞	∞	40.05	∞
2	5	20.98	26.83	33.99	24.73	30.59
2	6	22.49	25.63	27.69	26.53	29.68
2	7	24.79	27.64	29.70	29.62	32.47
2	8	27.25	29.47	31.07	32.31	34.53
3	5	25.93	27.73	29.19	31.17	32.97
3	6	29.67	30.93	31.87	35.79	37.04
Candidate b. LARC-V + Supplemental LCM-8						
1	8	36.26	∞	∞	38.80	∞
2	5	20.25	26.10	33.24	23.48	29.33
2	6	21.76	24.91	26.95	25.28	28.43
2	7	24.07	26.92	28.96	28.37	31.21
2	8	26.53	28.74	30.34	31.33	33.56
3	5	25.20	27.01	28.45	30.13	31.93
3	6	28.92	30.18	31.12	34.27	35.53
Candidate c. LARC-XV + Supplemental BARC						
1	8	36.55	∞	∞	38.65	∞
2	5	20.83	26.69	25.46	23.14	28.98
2	6	22.20	25.35	24.87	24.49	27.64
2	7	24.58	27.43	27.10	27.25	30.10
2	8	26.48	28.70	28.51	29.00	31.22
3	5	25.76	27.57	27.54	28.82	30.62
3	6	29.23	30.49	30.55	32.28	33.54

TABLE 23 (CONTINUED)

Arrangement		1-Mile Organization			3-Mile Organization	
Ship Disch.	Hatch Gangs	LEI Normal $x1000	LEI Weather $x1000	LEI Distance $x1000	LEI Normal $x1000	LEI Weather $x1000
Candidate d. LARC-XV + Supplemental LCM-8						
1	8	35.82	∞	∞	34.40	∞
2	5	20.11	25.96	24.73	21.89	27.73
2	6	21.47	24.62	24.14	23.23	26.38
2	7	23.92	26.77	26.44	26.00	28.84
2	8	25.77	27.99	27.80	28.65	30.88
3	5	25.04	26.84	26.81	27.57	29.37
3	6	28.50	29.76	29.82	31.04	32.29
Candidate e. BARC						
1	8	42.40	∞	∞	43.53	∞
2	5	28.37	34.22	29.96	30.54	36.40
2	6	31.60	34.75	32.59	33.77	36.92
2	7	35.87	38.72	36.86	38.04	40.89
2	8	40.02	42.24	40.73	42.19	44.42
3	5	38.01	39.81	38.70	41.22	43.02
3	6	44.27	45.53	44.81	47.48	48.74
Candidate f. LCM-8						
1	8	38.87	∞	∞	39.50	∞
2	5	24.14	30.00	24.52	24.78	30.62
2	6	26.40	29.55	26.67	27.03	30.18
2	7	29.70	32.55	30.08	30.34	33.18
2	8	32.89	35.10	33.68	34.07	36.29
3	5	31.64	33.44	31.86	32.54	34.34
3	6	36.44	37.71	36.67	37.35	38.61

TABLE 23 (CONTINUED)

Arrangement		1-Mile Organization			3-Mile Organization	
Ship Disch. Groups	Hatch Gangs	LEI Normal $x1000	LEI Weather $x1000	LEI Distance $x1000	LEI Normal $x1000	LEI Weather $x1000
Candidate g. LCU						
1	8	45.51	∞	∞	45.54	∞
2	5	31.68	37.52	32.16	33.22	39.07
2	6	35.85	39.00	36.18	37.39	40.54
2	7	41.07	43.92	41.40	42.61	45.46
2	8	46.15	48.37	46.46	46.19	48.41
3	5	42.91	44.72	43.00	45.22	47.02
3	6	50.59	51.85	50.78	52.90	54.16
Candidate h. CH-47 + Supplemental BARC						
1	8	44.40	∞	∞	51.80	∞
2	5	31.41	32.61	∞	41.09	42.30
2	6	33.71	34.46	41.98	45.68	46.43
2	7	38.08	38.83	46.36	51.31	52.06
2	8	42.56	43.13	47.06	56.82	57.39
3	5	41.82	42.27	∞	56.09	56.53
3	6	46.69	47.06	56.02	64.91	65.27



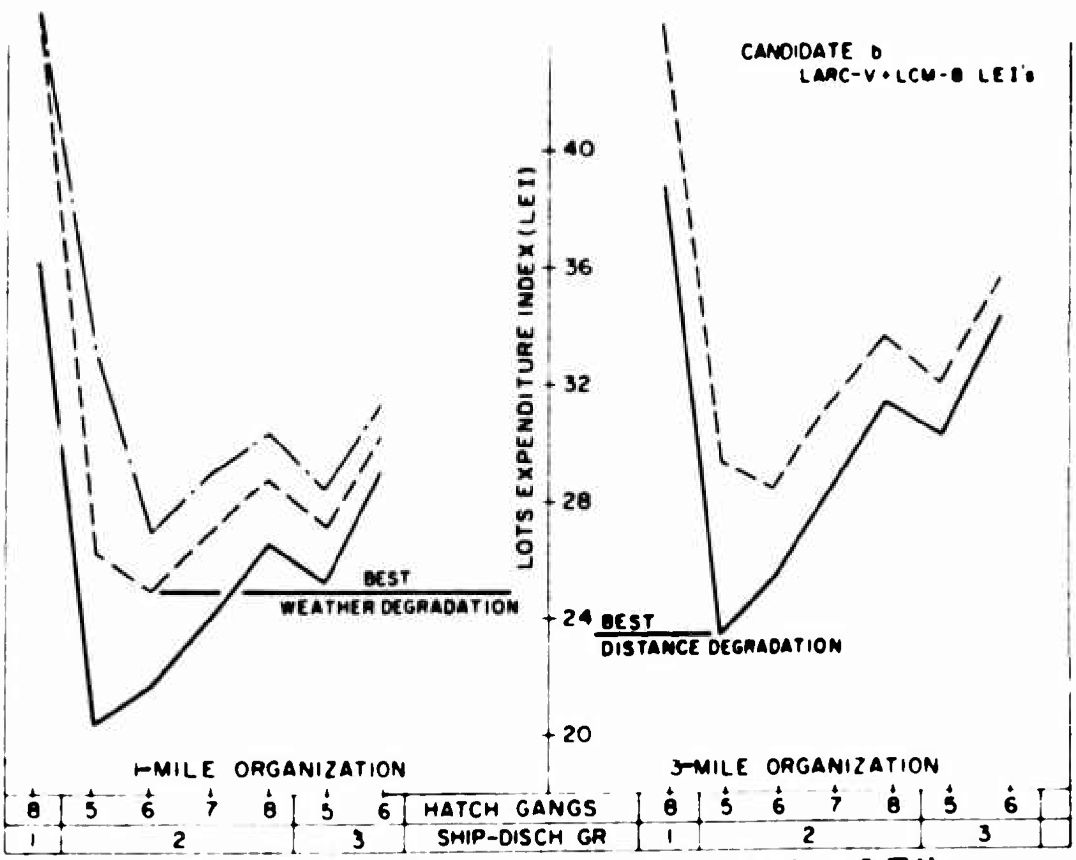


Figure 10. Normal and Degradation LEI's for LOTS System Candidates (Sheet 1 of 4)

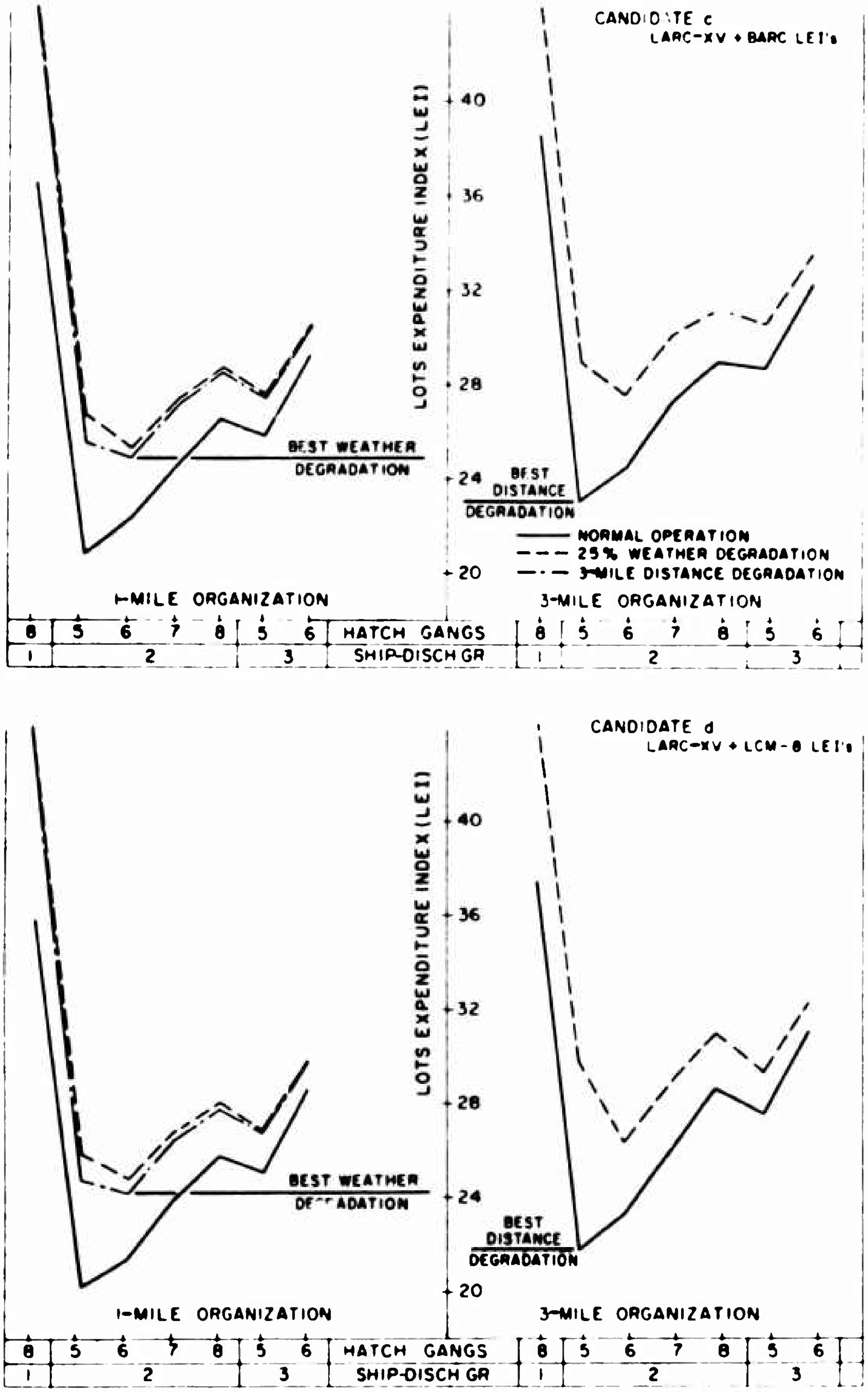


Figure 10. Normal and Degradation LEI's for LOTS System Candidates (Sheet 2 of 4)

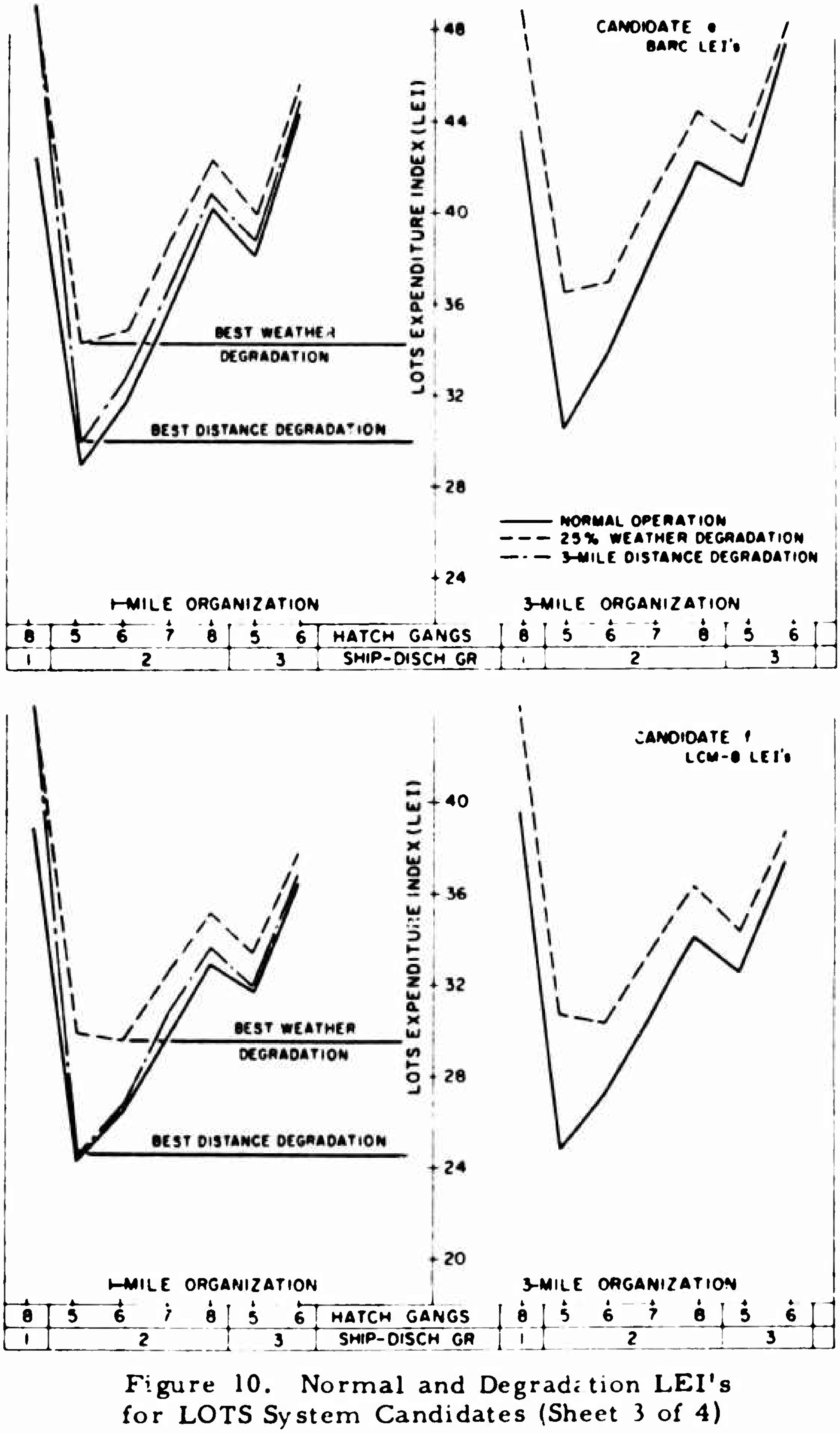
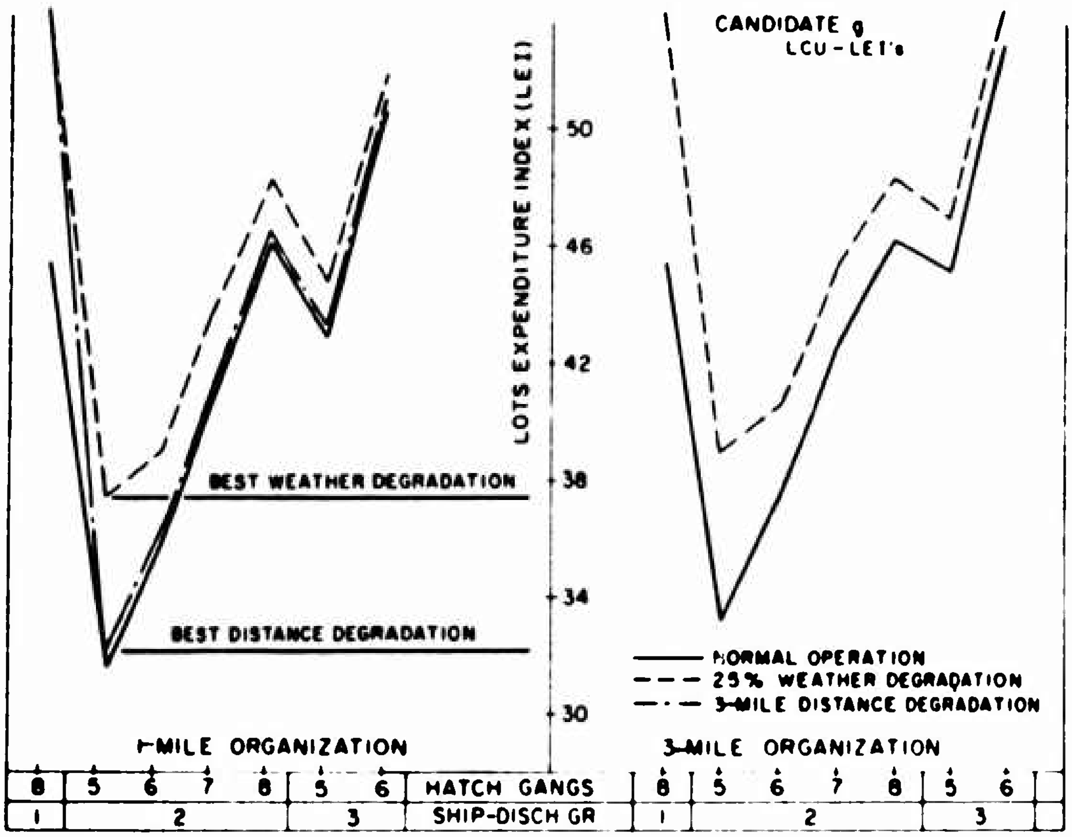


Figure 10. Normal and Degradation LEI's for LOTS System Candidates (Sheet 3 of 4)



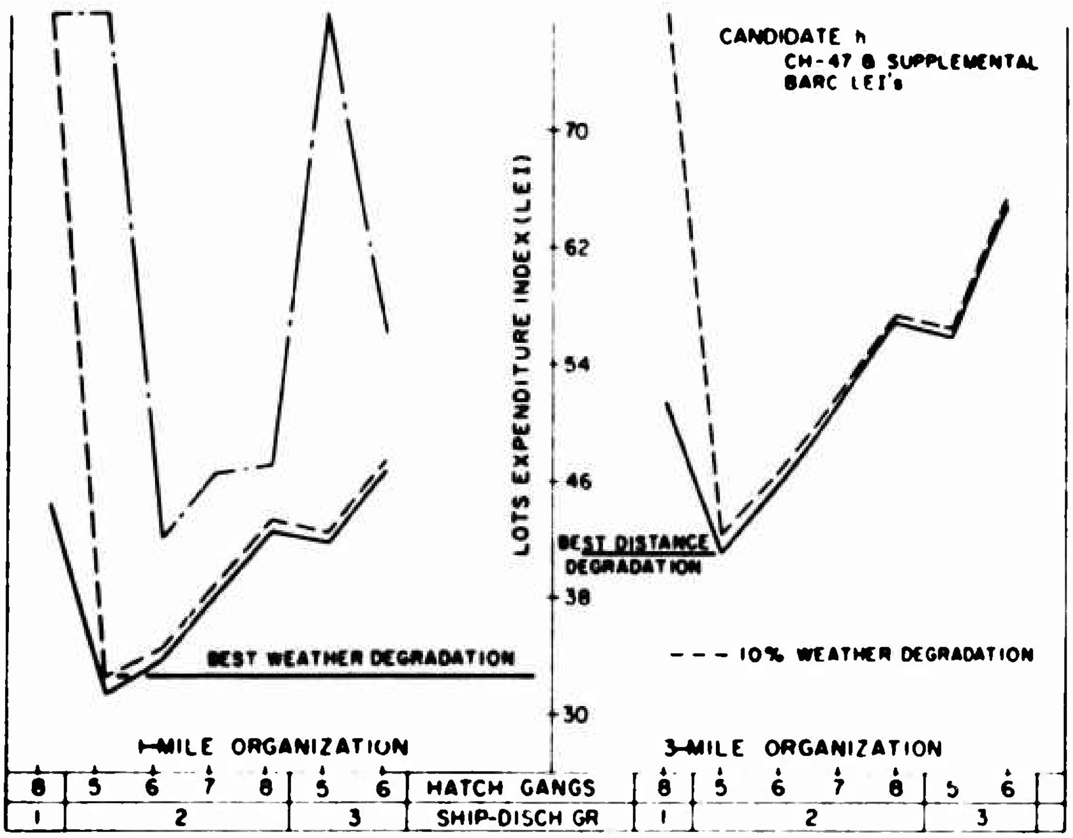


Figure 10. Normal and Degradation LEI's for LOTS System Candidates (Sheet 4 of 4)

TABLE 24
PREFERRED CANDIDATE SYSTEM ARRANGEMENTS
FOR MINIMUM LEI

		LOTS Expenditure Index $x1000		
Candidate	Arrangement[1]	Nominal Operation	Weather Degradation	Distance Degradation
a				
LARC-V	6 x 2 (1)	22.5	25.6	27.7
+ BARC	5 x 2 (3)	24.7	30.6	24.7
b				
LARC-V	6 x 2 (1)	21.8	24.9	27.0
+ LCM-8	5 x 2 (3)	23.5	29.3	23.5
c				
LARC-XV	6 x 2 (1)	22.2	25.3	24.9
+ BARC	5 x 2 (3)	23.1	29.0	23.1
d				
LARC-XV	6 x 2 (1)	21.5	24.6	24.2
+ LCM-8	5 x 2 (3)	21.9	27.7	21.9
e				
BARC	5 x 2 (1)	28.4	34.2	30.0
f				
LCM-8	6 x 2 (1)	26.4	29.6	26.7
	5 x 2 (3)	24.8	30.6	24.8
g				
LCU	5 x 2 (1)	31.7	37.5	32.2
h				
CH-47	5 x 2 (1)	31.4	32.6	∞
+ BARC	5 x 2 (3)	41.1	42.3	41.1
	6 x 2 (1)	33.7	34.5	42.0

1. Number of hatch gangs x Number of ship-discharge groups (distance to ship anchorages).

2. Candidate systems e, f, g, and h all result in high LEI's and should not be considered for operations in use.

3. Were it possible to quantitatively evaluate the effects of geographic variations, such weightings would be applied at this point in the analysis. However, a qualitative evaluation provides the following observations of comparative merits of the above candidates:

   a. Beach gradient varies considerably from place to to place and so do surf conditions — even along the same shore line. The use of landing craft for vehicular discharge requires good gradient conditions in order to avoid swamping the vehicles during discharge. Similarly, depending on the sand conditions and depth of the beach, vehicles may have difficulty clearing the area. This condition can be overcome by the use of pierced planking. The cost of the engineer activity in preparing the beach is not included in this study but could represent a high manpower cost.

   b. BARC's, although limited to wide roads by their size, have the capability of leaving the beach without the need for special engineering preparation.

It would, therefore, appear that some additional element of cost should be added to the LEI of families in which landing craft are included to cover the beach preparation and the need for tractors, etc.

STEP 4 — IDENTIFICATION OF AREAS FOR INVESTIGATION

In Steps 1, 2 and 3, numerical data was derived which provided the elemental costs of ships, equipment and personnel for the various candidate systems. Further, when summarizing these costs and considering the degrading influence of bad weather and dispersion distance it is observed that:

1. Were it not for the significant increase in ship cost resulting from 25 percent weather degradation, smaller LOTS organizations with lower normal LEI's (two ship-discharge group/five-hatch gang) could be utilized,

rather than the generally recommended two ship-discharge group/six-hatch gang arrangements.

2. From Figures 4, 5 and 6 and equation (1), it is observed that the lighter loading rates at the ship and at shore directly influence the number of lighters and lighter personnel required to perform a LOTS operation. Reduction in the time required to load each lighter at the ship could result if cargo were pregrouped into large, consolidated lifts in the hold or on deck prior to transfer into the lighter. Similarly, at the shore transfer location, consolidated lifting could reduce lighter discharge time. A reduction in the lighterage and personnel requirement could thereby result.

A numerical example of potential improvement in LEI is depicted in Figure 11. In this example, elemental costs are initially shown for ships, personnel, equipment and 25 percent weather degradation for two arrangements of candidate d systems. These are identified as "Present Loading" LEI's. The potential reduction in lighterage and lighterage personnel resulting from preconsolidated loading and discharge described above, is next plotted and identified as "Improved Loading" LEI. Finally, the reduction in ship waiting cost resulting from a notional device which would reduce weather degradation from 25 percent to 10 percent, is depicted.

The net percentage of improvement in LEI potentially obtainable is 24 percent. This represents the reduction in LEI which might result when an "Improved" two ship-discharge group, five-hatch gang organization is substituted for an "Improved" two ship-discharge group, six-hatch gang organization. Further analysis of the elemental costs depicted in Figure 11 reveals that personnel costs represent approximately 60 percent of the total normal LEI of each candidate system. This determination establishes the desirability of further investigation of improved techniques and equipment to minimize shipboard and shore transfer stevedoring personnel.

While it is unrealistic to envision large automatic systems of the type now used to discharge container ships being put to use in 20-year-old C-2 ships, it is reasonable to consider taking advantage of increases and standardization of unitization that have already occurred in devising means of reducing personnel on the ship. New equipment, even

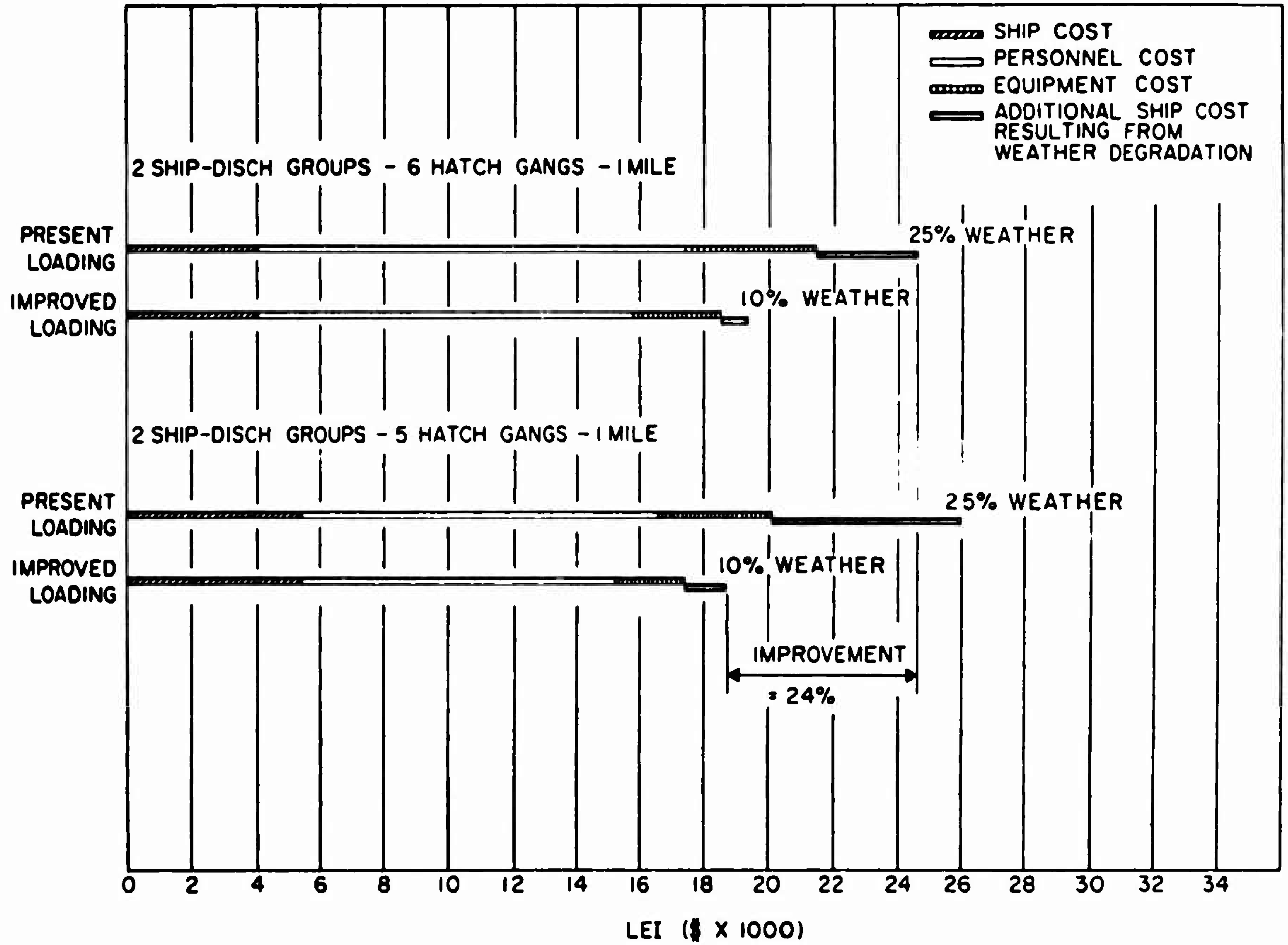


Figure 11. Example of Potential Improvement in LEI

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if initially priced as high as the cost of a LARC-XV, for example, would have an amortization write-off equivalent to the daily cost of five military stevedores. It would seem that such equipment could readily reduce the hatch TOE by 5/40ths (12 percent) and, in addition, decrease ship discharge time.

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APPENDIX
PRELIMINARY INVESTIGATION OF TECHNIQUE AND EQUIPMENT IMPROVEMENTS

The body of this report indicates that significant improvement can be achieved in the LOTS Expenditure Index by:

1. Reduction in lighter loading time.

2. Reduction in weather degradation.

3. Reduction in personnel required.

This appendix considers methods of accomplishing such reductions through improvements in equipment and/or techniques. Qualitative and quantitative evaluation of these improvements will be provided in the Phase II report.

REDUCTION IN DISCHARGE TIME

Improvements in Cargo Prestow

Although cargo prestow planners attempt to equalize loading time of all hatches, the immediate concern of achieving maximum space utilization in the ship normally takes precedence and the balanced discharge goal is severely compromised.

The reason for this is simple. Consider the following example. If an additional stowage loss of 10 percent occurs in achieving balanced hatch times, one additional round-trip voyage would be required every ten trips considered. A round-trip cycle for a ship to a distant shore may require forty days or more. Thus, the breakeven point would be reached if four days cycle time were saved in each ship loading and discharge by balancing hatch times.

The point overlooked, however, in this oversimplified analysis is whether potential saving in the cost of discharge operations will offset the cost of the extra voyages.

The RO-RO vessels are an illustration of this approach, and so might be either or both of the cargo prestow techniques recommended below.

1. Establishment of wartime standard resupply and prestow plans for each ship class.

2. Prestow complete levels of hatches with a specific type of cargo (i.e., all pallets or all drums, etc.).

Standard Prestows

It appears from analysis of FM 101-10 data that much of the resupply planning is accomplished on the basis of anticipated rates of consumption derived from past experience. Hence, in combination with the present practice of balanced stowage (eliminating ammunition ships and ships carrying specific organizational resupply), standard prestow plans appear to be feasible. Such prestow plans would allow sufficient space for supplies provided on a requisition basis. These would be individually planned for each shipment.

Optimum standard arrangements of cargo stowage could be achieved by analysis and test, thereby permitting the establishment of realistic planning factors and efficient discharge operations.

Block Stowage by Cargo Type

Without a reasonable level of standardization of modules to be handled, the task of replacing men with machines or minimizing discharge delays is extremely difficult. Stowage of singular-type cargo in specific areas of the ship is now standard practice, but only to a limited extent. The technique described here requires analysis of load and space limitations of holds in all active cargo ships.

Making Better Use of Ships' Gear

With the exception of some newer ships which have gantry cranes, most conventional dry cargo vessels carry double rigging equipment (i.e., four booms and four electric or steam-driven winches) over their long hatches and single rigs (two booms and two winches) over hatches 1 and 5. This equipment, when rigged for married-fall with one boom positioned over the hatch and the other over the side of the ship, offers self-contained loading and discharge capability.

LOTS operations, however, are primarily one-way operations — discharge. Therefore, were it not for the need to swing cargo laterally from the hatches over the side, only one winch and boom would be required to lift one hook. Similarly, if cargo could be moved laterally from the hatch to a position outboard of the railing by some means (gravity conveyor, for example), only a low-horsepower braking device would be required for lowering the hook. The second winch might then be made available to operate a second hook in the hold.

This discussion merely points out certain capabilities available on each ship which may be better utilized.

Influence of Hook Cycle on Discharge Time

Time studies previously referred to in this report and summarized in Table 6 described the hook cycle as the limiting factor in offshore discharge. University of California studies (reference 3) of pierside operations found the hook to be the most frequent cause of delay.

It is understandable why this is the case when one considers the dependency placed on the hook. In offshore operations, the hook is frequently used to drag cargo from the wings. Next, it waits while slings are added and hooked. The hook then swings the draft out over the deck to a position just above the lighter. At this point in the operation, the winchman, following signals from the signalman, inches the cargo into the lighter while the lighter crew move the draft into proper position. Again, the hook must wait for the slings to be removed before it can be swung back into the hold.

While these operations have been going on, the hatch gang, divided into two "corner" groups, may have already moved two drafts into the square for attachment to the hook, or they may be waiting for the hook to return to permit attachment to a drag line.

From the foregoing discussion, it is evident that the existing ship's hook is "overworked".

Several solutions are available to improve this condition:

1. Reduce hook cycle time — The most effective means of reducing hook cycle time is to curtail hook activities.

   Method (a) — Eliminate use of hook dragging cargo in the hold. This involves the employment of other prime movers in the hold for moving cargo from the wings.

Method (b) — Eliminate use of hook for lighter loading by requiring the hook only to bring cargo to the deck where other equipment would be provided for lighter loading.

2. Add more hooks — The addition of hooks to the hold will permit parallel operation comparable to double-rig operations.

3. Require fewer hook cycles — Ship riggings have safe working loads of four tons and more, yet they are most frequently used to lift considerably lighter drafts. The main exception to this is container discharge. By combining several modules of cargo into single four-ton lifts before slinging and lifting, fewer hook cycles will be required, thus permitting the hook to remain in the hold for dragging and lifting.

Concept 1 — Portable Winches for Use in Hold

Purpose — Eliminate use of ship's hook for dragging cargo from wings.

Description of Equipment

1-1/2 to 2-Ton/50-60 f.p.m. electric winches mounted on adjustable tripods that may be hung from the hatch coaming and wedge against the deck under load.

Operation

Equipment is lowered into the hold when stevedores go down; the winch and tripod assembly is positioned under the coaming and used to pull cargo from the wings. Double reeving, or use of two winches, is required for heavy loads.

Concept 2 — Slave Pallet Discharge and Transfer System. (See Figures 12, 13 and 14)

Purpose — Speed up ship and shore discharge operations by

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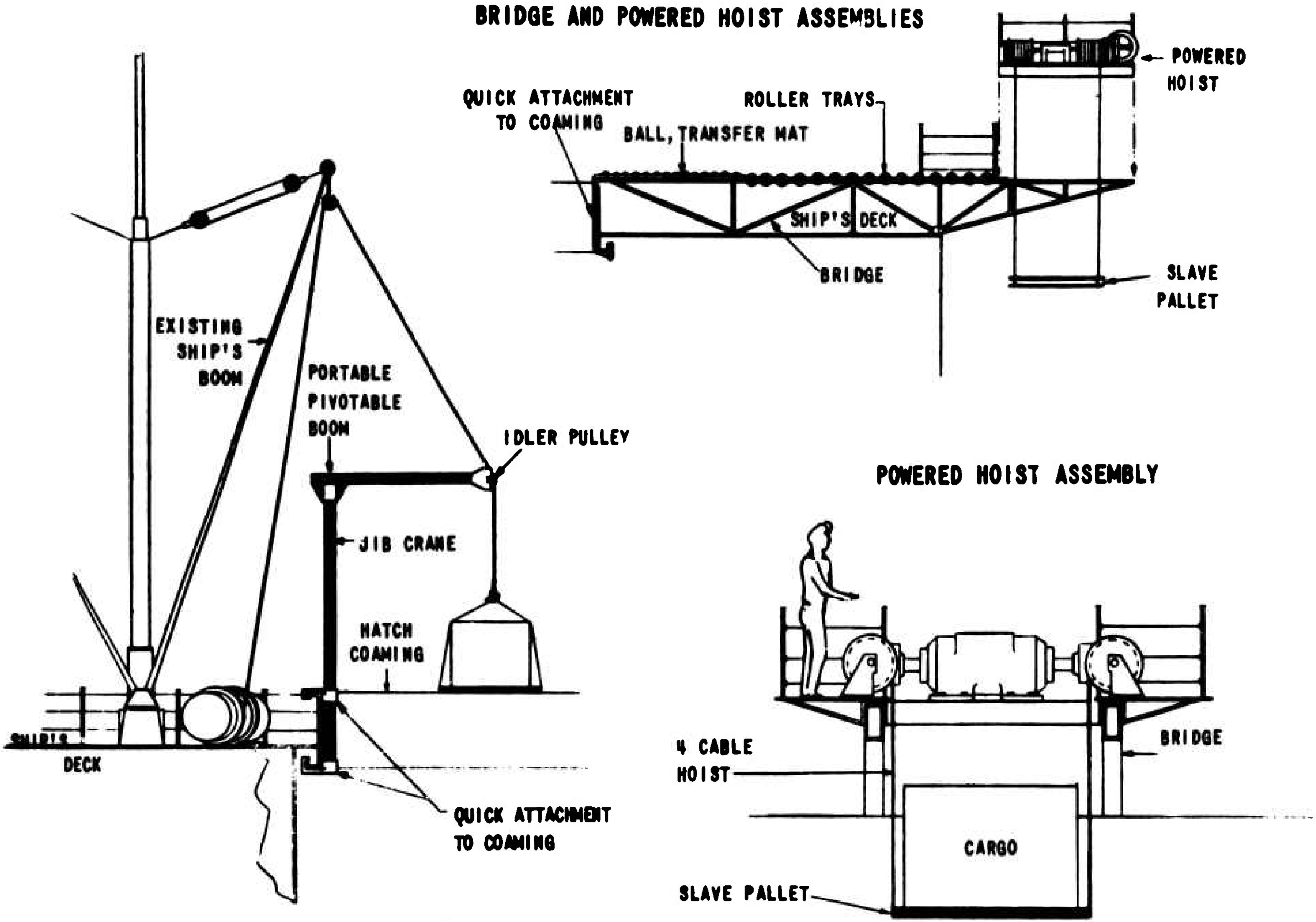

Figure 12. Components of Slave Pallet Discharge and Transfer System

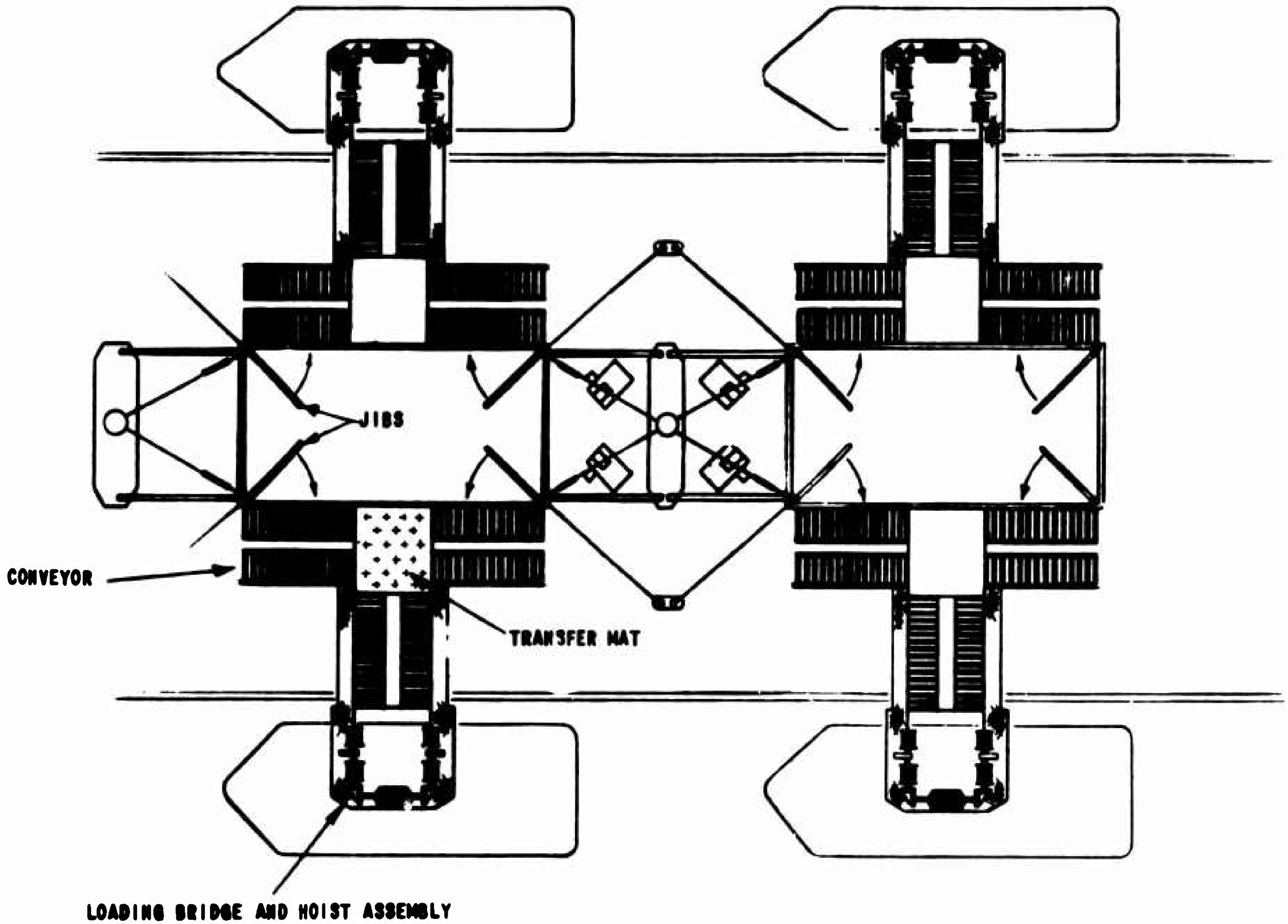

Figure 13. Plan View of Slave Pallet Discharge and Transfer System

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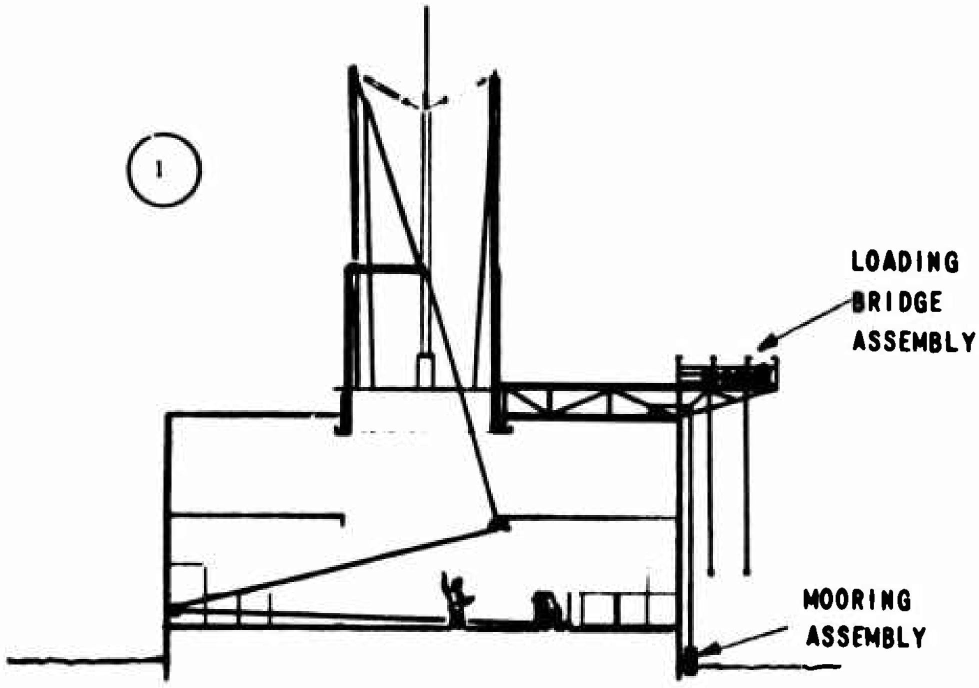
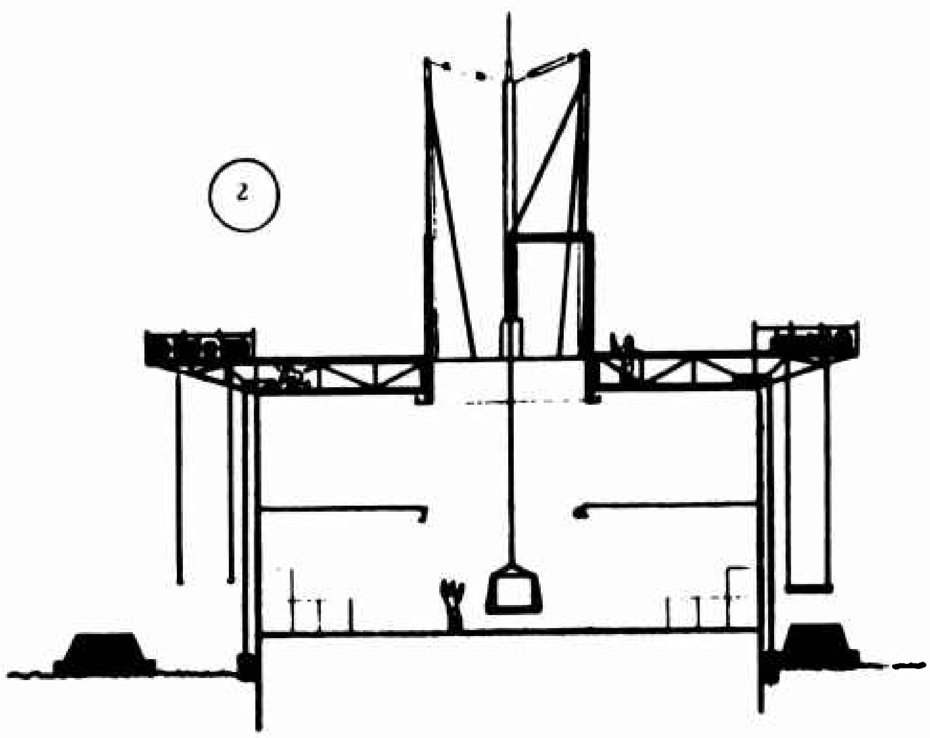
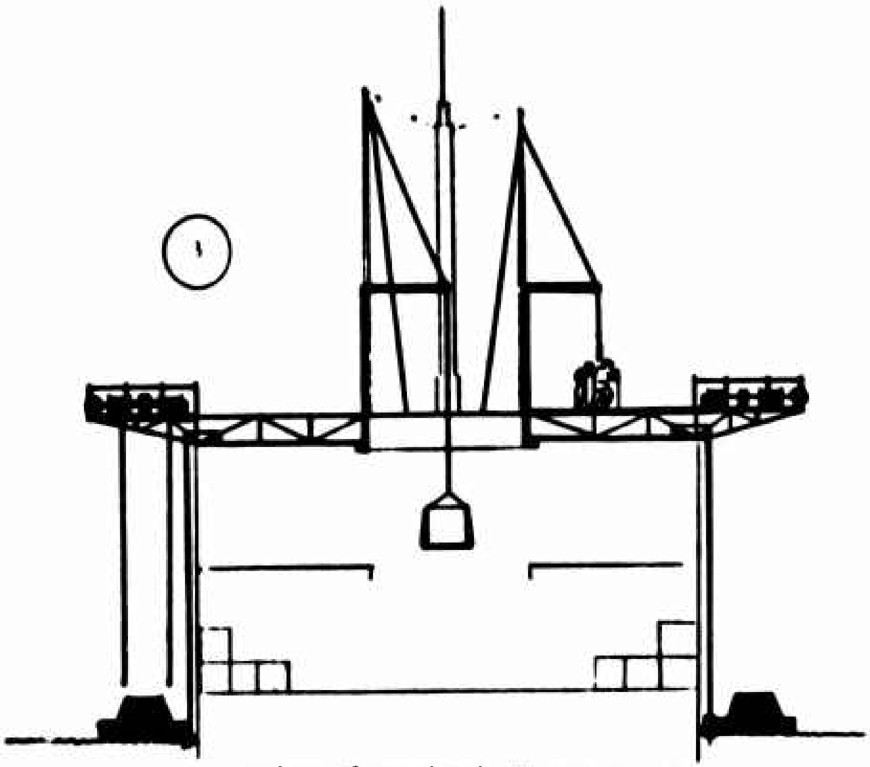


CARGO DRAGGED TO SQUARE USING JIB AND SHIP'S WINCH, WHILE BRIDGE AND MOORING ASSEMBLIES ARE INSTALLED

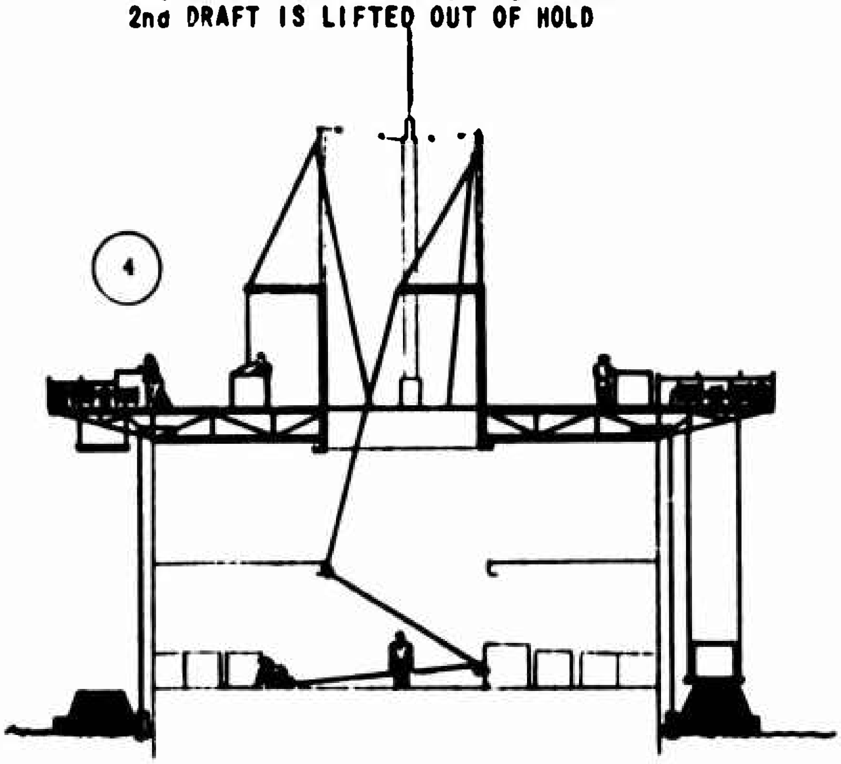


DRAFT LIFTED OUT OF HOLD AND
EMPTY SLAVE PALLET RAISED FROM LIGHTER

Figure 14. Operational Sequence — Slave Pallet Discharge and Transfer System (Sheet 1 of 2)



1st DRAFT MOVED ONTO BRIDGE WHILE
2nd DRAFT IS LIFTED OUT OF HOLD



DRAFTS ON SLAVE PALLET LOWERED INTO LIGHTER
WHILE MORE DRAFTS ARE MOVED ONTO BRIDGE

Figure 14. Operational Sequence – Slave Pallet Discharge and Transfer System (Sheet 2 of 2)

providing:

1. Additional hooks.
2. Intermediate storage on deck.
3. Rapid loading of lighter.
4. Rapid discharge of lighter.

Description of Equipment

1. Portable jib cranes with clamps for connection to hatch coaming.
2. Loading bridge with tension clamp for connection to coaming.
3. Deck conveyor sections.
4. Removable, powered drive skid with four cable hoists suitable for lowering 5-ton drafts at 100 feet per minute.
5. Slave pallet (false floor for lighters) approximately 8 feet by 6 feet. May be lifted by four cables or fork-lift.

Operation

1. Jib cranes permit ship winches to be used individually, thereby creating parallel hook paths in and out of the hold. Similarly, they can be used for dragging cargo from the wings.
2. Individual drafts of cargo are placed on the conveyor and moved to the bridge.
3. Plywood panels are placed along the conveyor when drums are being discharged. Nets are placed on single plywood panels which serve as pallets.

4. When the lighter arrives, its slave pallet is hoisted into position in the bridge. Four pallets or one container or general cargo or drums are moved onto it.

5. The load is lowered under the control of a four-corner cable system into the lighter (LARC-V's carry one slave pallet; LARC-XV's carry three or four slave pallets).

6. When the lighter reaches shore, a forklift, A-frame or hoist is used to lift the slave pallet out. An empty slave pallet is then set in place, enabling the lighter to move out while cargo is being removed from the original slave pallet.

Advantages

1. Enables continuous hook operations with little or no delay by providing additional hook and an intermediate storage area on deck.

2. Reduces the number of lowering cycles into the lighter, enabling the lighter to move out more quickly.

3. Minimizes swinging of cargo by providing four-cable lift.

4. Conveyors could be extended to join hatches. This would help minimize degradation resulting from frequent closing down of hatches 1 and 5 in bad weather.

5. A longer bridge design may permit use of equipment as helicopter wing if required.

6. Drive system permits operator visibility of lighter for safety. If required, pendent control could be lowered to lighter.

REDUCTION IN WEATHER DEGRADATION

The following equipment and techniques are currently being considered for possible employment in LOTS bad weather operations.

1. Lighter mooring device.

2. Draft guide assembly.

3. Slave pallet discharge system previously described. See Figures 12, 13 and 14.

4. Highline to BDL.

Lighter Mooring Device

Purpose — Permit safe mooring of small lighters in heavy sea.

Description of Equipment (See Figure 15)

1. Floating bumper assembly carries mooring links. The mooring links are spring-actuated in an extended position. The bumper assembly is buoyed by air bags and guided on a quick-connecting structural assembly which rests on and is tied to the deck.

2. Two open mouth mooring hooks must be preinstalled on each lighter in the position of the existing lifting rings.

3. Equipment not shown includes a stevedore's boarding ladder which moves upward with movement of the bumper assembly, preventing injury to boarding personnel.

Operation

An approaching lighter guides against the bumper assembly, moving ahead to permit self-engagement of its special hooks around the mooring links. By maintaining forward tension against the links, the lighter is held close to the ship. Disengagement requires reversing or idling and drifting back.

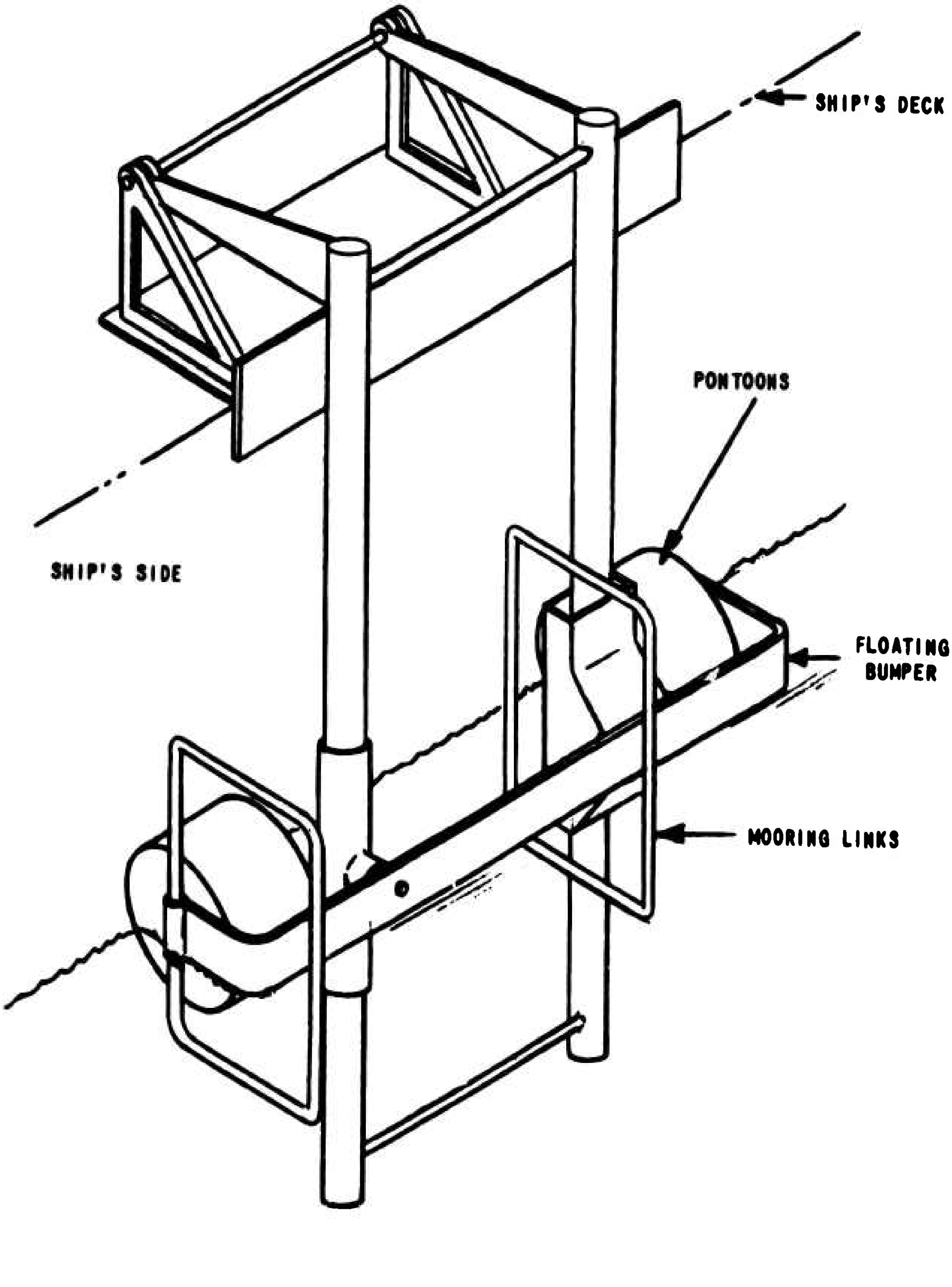


Figure 15. Lighter Mooring Device.

Advantages

1. Lighter is moored and held safely against the side of the ship without the need for personnel leaning over to attach lines.

2. Personnel have safe means of transfer.

Draft Guide Assembly

Purpose – Guide cargo drafts into lighters in heavy seas.

Description of Equipment (See Figures 16 and 17)

1. A retractable guide-rail assembly operated from a removable bridge assembly.

2. Power-operated guide fingers raised by a winch on the bridge.

Operation

1. An arriving lighter moors with the aid of the mooring device previously described.

2. The guide rail is lowered to the deck of the lighter, where it is pinned into position. The guide rail is free to float up and down with the lighter.

3. Cargo drafts are swung into position over the bridge by the ship's gear.

4. Guide fingers are energized against the base of the draft to hold it securely in proper position. Should it be desired to intentionally offset the draft relative to the center of the lighter, this can be achieved by use of fingers without re-rigging the boom.

5. The draft is then lowered by the ship's hook and guided by the fingers.

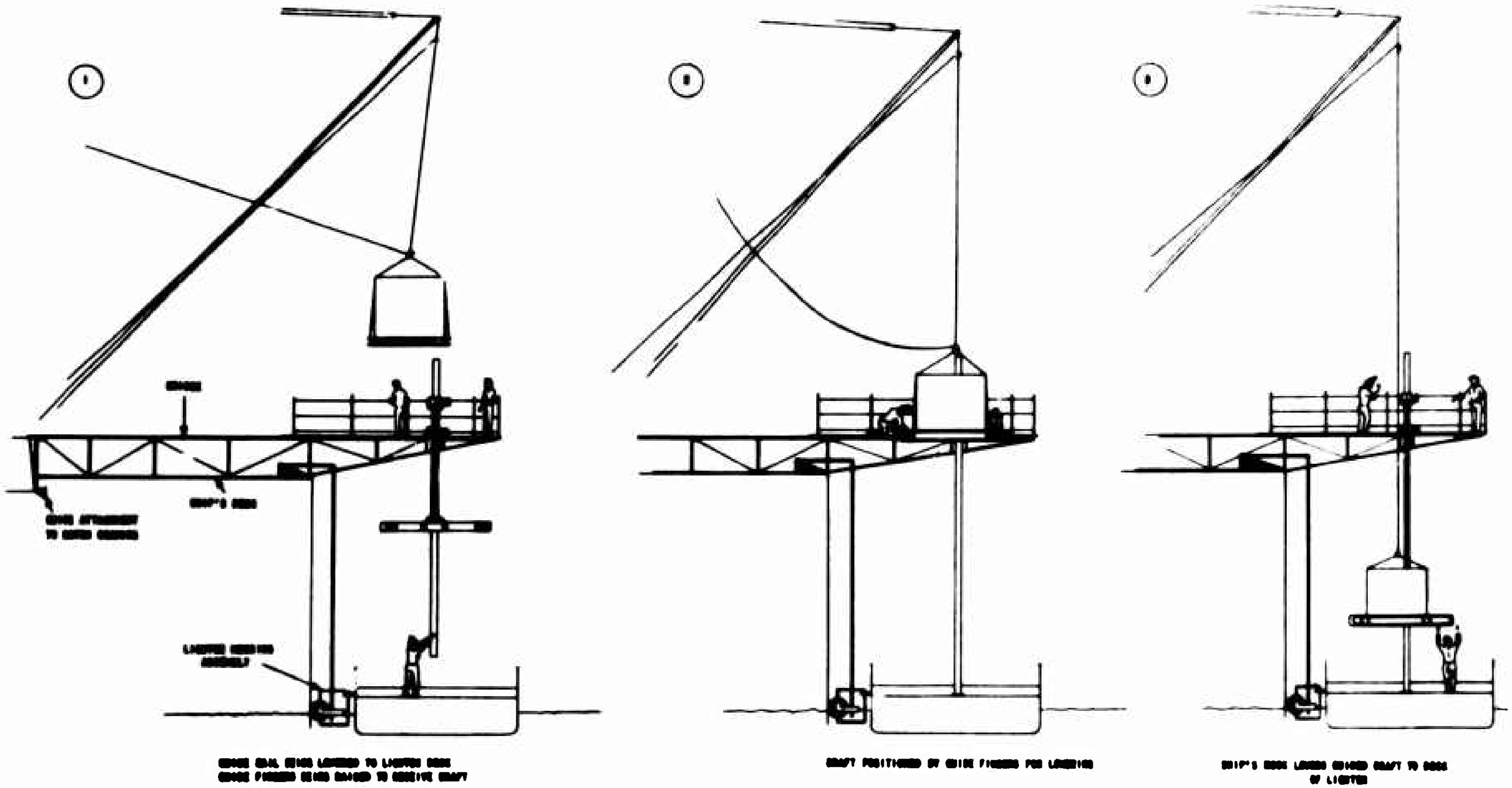


Figure 16. Operational Sequence – Cargo Draft Guide Assembly

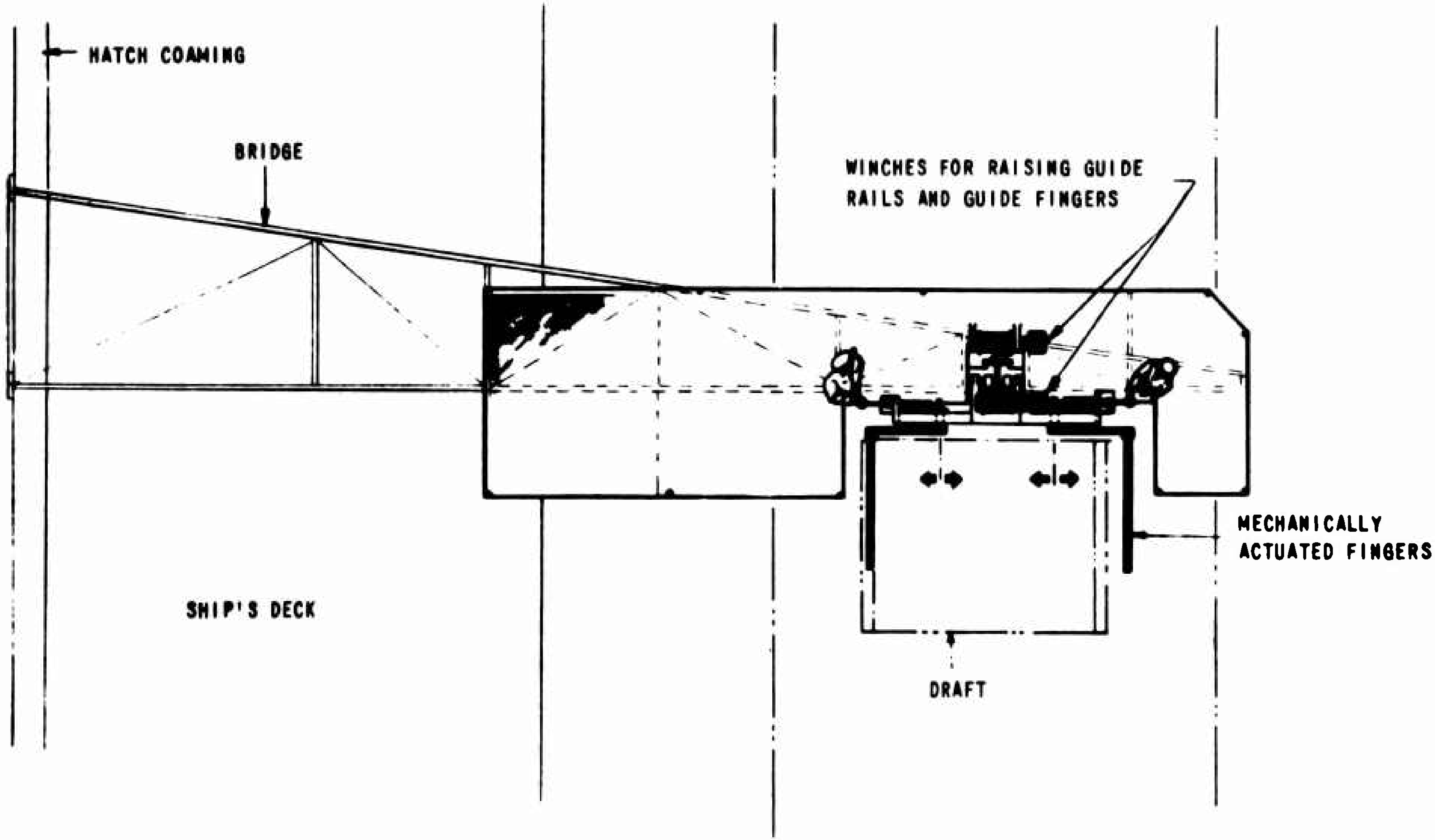


Figure 17. Plan View – Cargo Draft Guide Assembly

6. The hook fingers and guide rail are then released permitting them to be raised to clear the lighter.

Highline to BDL

It is anticipated that the BDL will be unable to achieve marriage with RO-RO shipping in bad seas. It is therefore assumed that BDL's will be available for other uses at such times.

It is proposed that mobile highline equipment similar to the modified LCVP used in BuShip tests (reference 8) be brought aboard the BDL while it is at shore. A BARC or equivalent will carry the A-frames and flounder plates of two highline devices to the ship for pickup by the boom. Once installed, each equipment will be capable of delivering cargo at the rate of one load per minute.

Two techniques of highline operation are briefly considered here. Further investigation is required to determine feasibility of each technique.

Amphibian Operation (See Figure 18)

The ramp of the BDL would be partially buoyed by the installation of suitable pontoons. Amphibians will approach the ramp and pick up a winch line, which will assist their ascent up the ramp. Once on board, the amphibians will be rotated on a turntable and either assigned to one of the highlines or held in queue aboard. Following loading, the amphibian departs down the ramp and into the water.

RO-RO Highline (See Figure 19)

In this approach, empty flat-bed semitrailers are loaded onto the BDL at the shoreline. The highline machines are moved along the BDL as they complete loading each semitrailer, until all trailers are loaded. The highlines are then detached and the BDL returned to shore, where the trailers are taken off by tractors.

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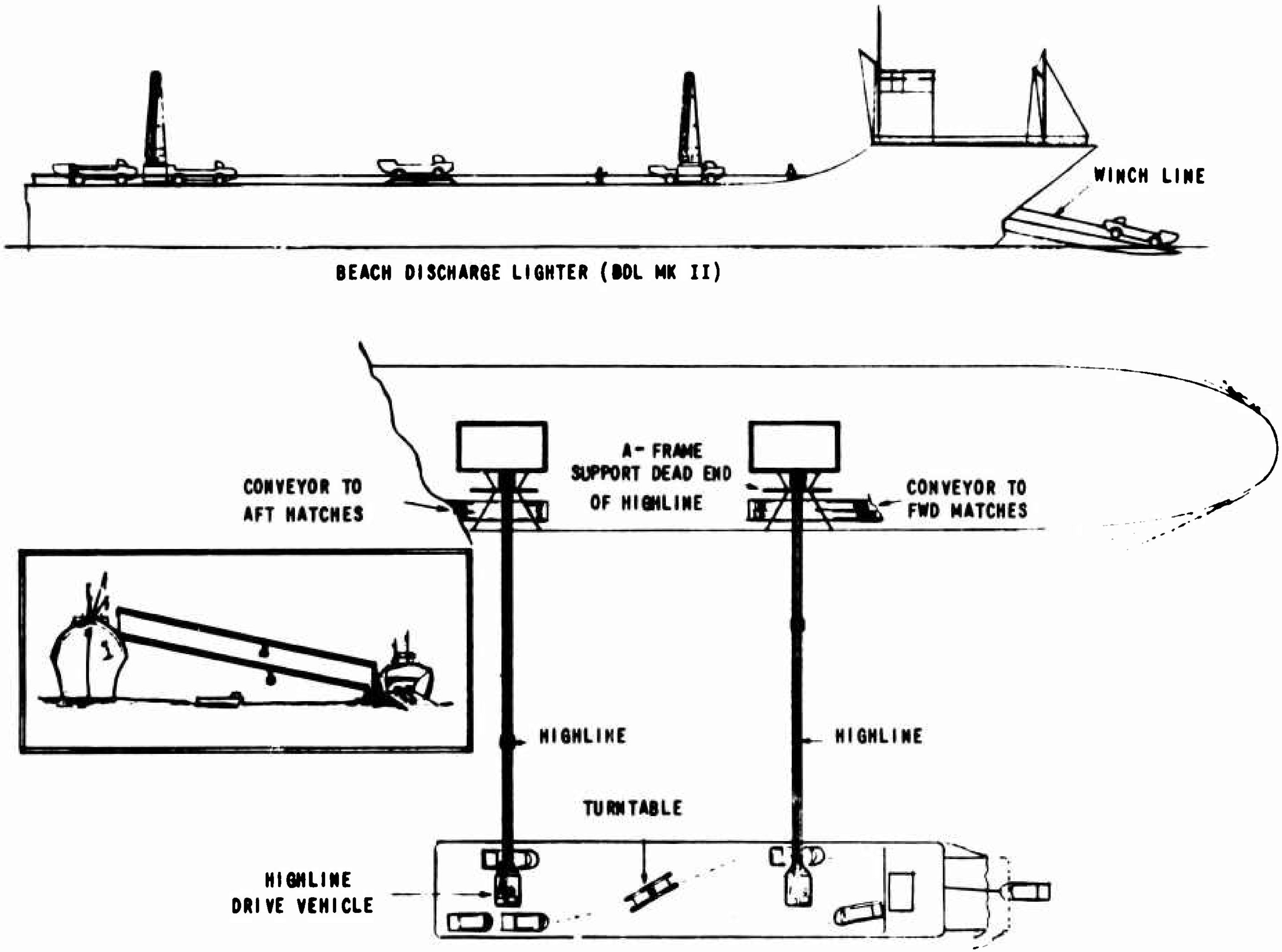

Figure 18. Highline/BDL Transfer Operation with Amphibians.

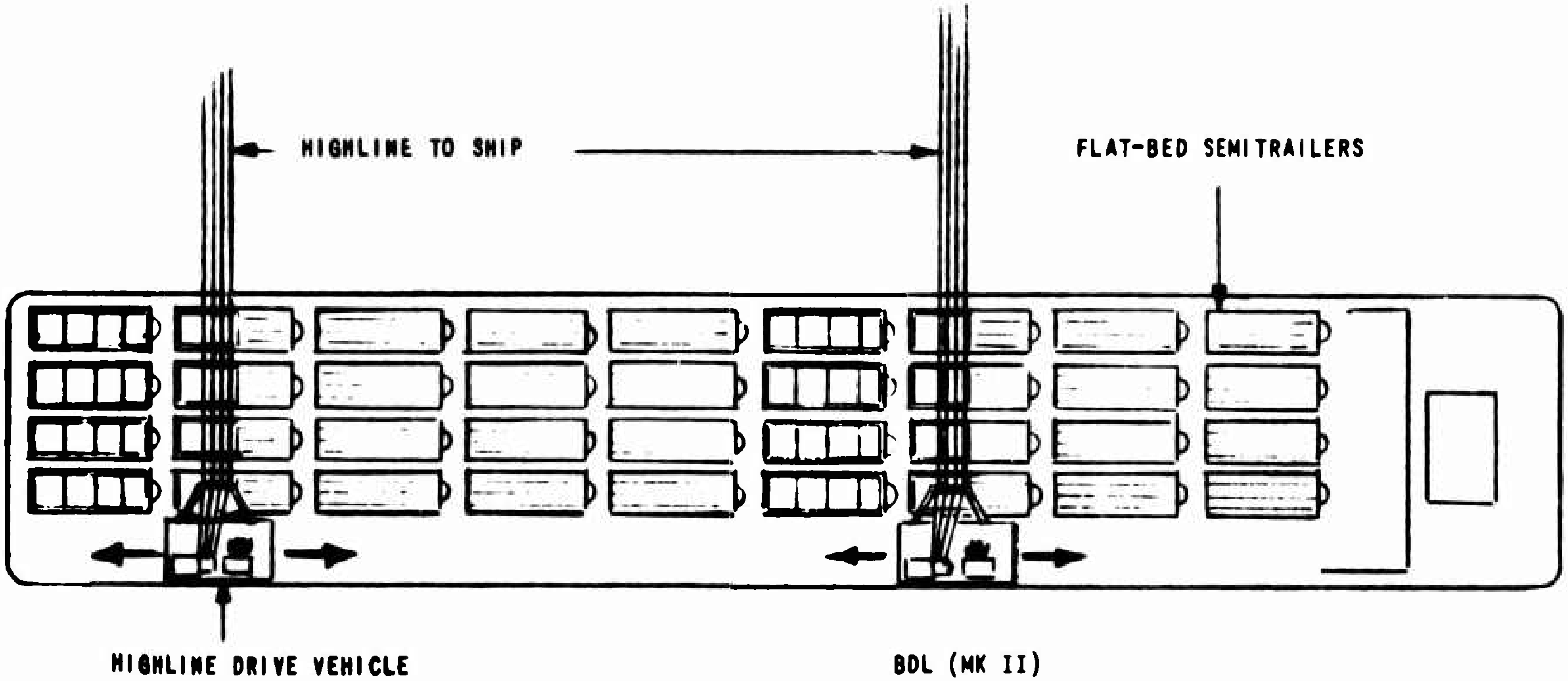

Figure 19. Highline/BDL Transfer Operation with Flat-Bed Semitrailers

REDUCTION IN PERSONNEL REQUIRED

Each preceding equipment and technique concept has a direct effect on personnel utilization by:

1. Decreasing average ship discharge time.

2. Replacing men with low-cost equipment.

Other personnel savings can be achieved by improvements in the techniques and equipment utilized ashore.

The use of side-opening and ramp-opening amphibians minimizes the difficulty of lighter discharge; similarly, extensions in the use of unitized resupply further creates an atmosphere for personnel reduction in shore discharge operations. Such reduction could be accomplished by the adoption of transit techniques permitting only unitized cargo to be discharged at specified locations where special mechanical handling equipment is available (i.e., A-frames, rough-terrain forklifts, etc.).

The Phase II study report will provide estimates of the quantitative effects on LOTS Expenditure Index of the techniques and equipment improvements contained herein.

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